RANDALL

The Emergency Butterfly Dam
On the Chicago Drainage
Canal at Lockport, Illinois

Civil Engineering
C. E.
1909

THE EMERGENCY BUTTERFLY DAM ON THE CHICAGO DRAINAGE CANAL AT LOCKPORT, ILLINOIS

BY

FRANK ALFRED RANDALL

B. S. University of Illinois, 1905

THESIS

Submitted in Partial Fulfillment of the Requirements for the

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IN

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OF THE

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1909

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THE GRADUATE SCHOOL

May 18, 1909

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK ALFRED RANDALL

ENTITLED THE EMERGENCY BUTTERFLY DAM ON THE CHICAGO DRAINAGE CANAL AT LOCKPORT, ILLINOIS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Civil Engineer

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Committee on Final Examination

The Emergency Butterfly Dam.

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GENERAL DESCRIPTION OF THE LAYOUT OF THE SANITARY DISTRICT OF CHICAGO NEAR THE CONTROLLING WORKS AND POWER HOUSE AND IN THE VICINITY OF JOLIET.

The sanitary and ship canal was started September 3, 1892 and on January 2, 1900 water was turned in for first time. It took thirteen days to fill the channel down to the controlling works. Work on the water power extension was started four years later and finished in 1907, the head race being partially filled by the opening of the valves in the Butterfly Dam on August 30th of that year. The view of the dam which we use as frontispiece was taken at that time.

As will be noted from Fig. I, the main drainage channel which commences at Robey Street continues in a southwesterly direction down to Romeo, where it curves off to the south and extends to the power house south of Lockport. There are no locks between these points, the elevation of water surface being that of Lake Michigan.

Its minimum depth is 22 feet. The channel is cut partly through rock. From Robey Street to Summit, about eight miles, the channel is 110 feet at bottom and 198 feet at water line. From Summit to Willow Springs, about five miles, the channel is through earth and hard mixture. This section is 202 feet at

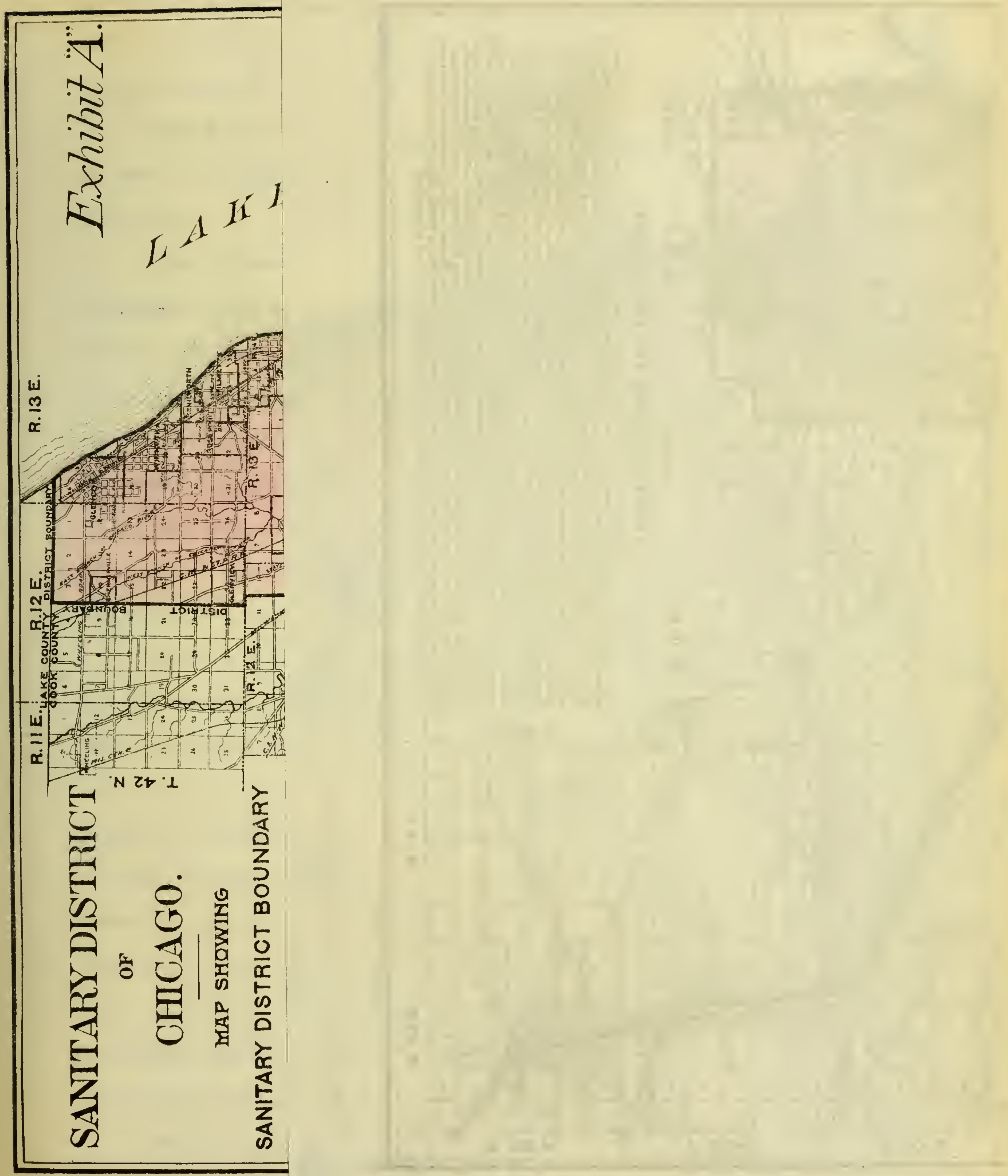


Exhibit "A".
SANITARY DISTRICT
OF
CHICAGO.
MAP SHOWING
SANITARY DISTRICT BOUNDARY
LAK
R. 11 E.
R. 12 E.
R. 13 E.
T. 42 N.
LAKE COUNTY
COOK COUNTY
DISTRICT BOUNDARY
BOUNDARY
DISTRICT
GLENCOE
KENILWORTH
R. 12 E.
R. 13 E.

Fig. 1.

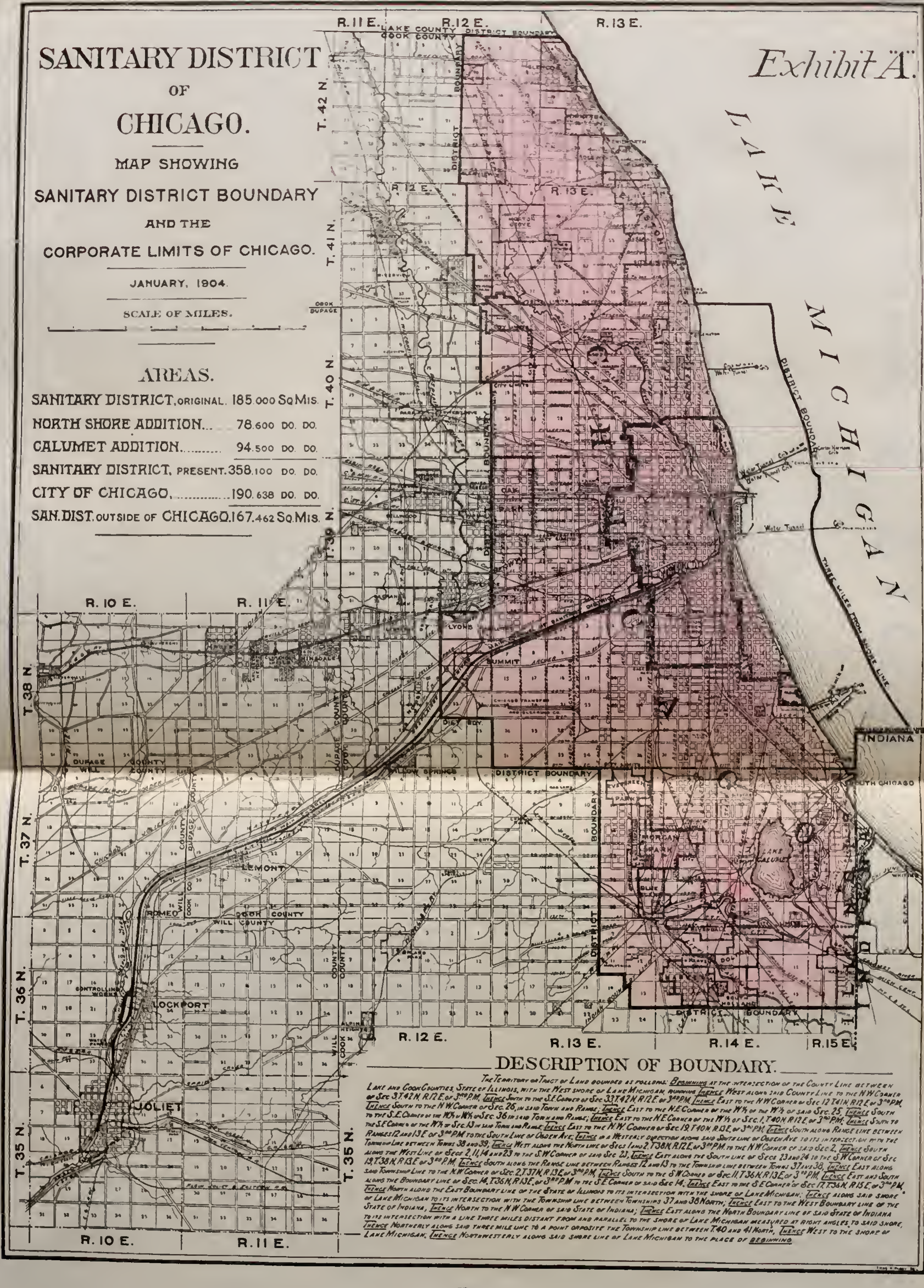


Exhibit "A".
SANITARY DISTRICT
OF
CHICAGO.
MAP SHOWING
SANITARY DISTRICT BOUNDARY
AND THE
CORPORATE LIMITS OF CHICAGO.
JANUARY, 1904.
SCALE OF MILES.
AREAS.
SANITARY DISTRICT, ORIGINAL. 185.000 SQ. MIS.
NORTH SHORE ADDITION... 78.600 DO. DO.
CALUMET ADDITION.......... 94.500 DO. DO.
SANITARY DISTRICT, PRESENT. 358.100 DO. DO.
CITY OF CHICAGO, ...190.638 DO. DO.
SAN. DIST. OUTSIDE OF CHICAGO. 167.462 SQ. MIS.
LAKE MICHIGAN
LAKE COUNTY
COOK COUNTY
DISTRICT BOUNDARY
INDIANA
SOUTH CHICAGO
LAKE CALUMET
LYONS
SUMMIT
LEMONT
ROMEO
LOCKPORT
JOLIET
CONTROLLING WORKS
WILLOW SPRINGS
OAK PARK
MORGAN PARK
BLUE ISLAND
HINSDALE
DUPAGE COUNTY
WILL COUNTY
COOK COUNTY
Water Tunnel
THREE MILES FROM SHORE LINE
R. 10 E.
R. 11 E.
R. 12 E.
R. 13 E.
R. 14 E.
R. 15 E.
T. 35 N.
T. 36 N.
T. 37 N.
T. 38 N.
T. 39 N.
T. 40 N.
T. 41 N.
T. 42 N.
DESCRIPTION OF BOUNDARY.
The Territory or Tract of Land bounded as follows: Beginning at the intersection of the County Line between Lake and Cook Counties, State of Illinois, with the West shore of Lake Michigan, running Thence West along said County Line to the N.W. Corner of Sec. 3, T. 42 N., R. 12 E. of 3rd P.M.; Thence South to the S.E. Corner of Sec. 33, T. 42 N., R. 12 E. of 3rd P.M.; Thence East to the N.W. Corner of Sec. 12, T. 41 N., R. 12 E. of 3rd P.M.; Thence South to the N.W. Corner of Sec. 26, in said Town and Range; Thence East to the N.E. Corner of the W½ of the W½ of said Sec. 25; Thence South to the S.E. Corner of the W½ of W½ of Sec. 36 in said Town and Range; Thence East to the N.E. Corner of the W½ of Sec. 1, T. 40 N., R. 12 E. of 3rd P.M.; Thence South to the S.E. Corner of the W½ of Sec. 13 in said Town and Range; Thence East to the N.W. Corner of Sec. 19, T. 40 N., R. 13 E. of 3rd P.M.; Thence South along Range line between Ranges 12 and 13 E. of 3rd P.M. to the South Line of Ogden Ave.; Thence in a Westerly direction along said South line of Ogden Ave. to its intersection with the Township Line between Towns 38 and 39; Thence West along the North line of Secs. 1 and 2, T. 38 N., R. 12 E. of 3rd P.M. to the N.W. Corner of said Sec. 2; Thence South along the West Line of Secs. 2, 11, 14 and 23 to the S.W. Corner of said Sec. 23; Thence East along the South line of Secs. 23 and 24 to the S.W. Corner of Sec. 19, T. 38 N., R. 13 E. of 3rd P.M.; Thence South along the Range line between Ranges 12 and 13 to the Township line between Towns 37 and 38; Thence East along said Township Line to the N.W. Corner of Sec. 2, T. 37 N., R. 13 E. of 3rd P.M.; Thence South to the S.W. Corner of Sec. 11, T. 36 N., R. 13 E. of 3rd P.M.; Thence East and South along the Boundary line of Sec. 14, T. 36 N., R. 13 E. of 3rd P.M. to the S.E. Corner of said Sec. 14; Thence East to the S.E. Corner of Sec. 17, T. 36 N., R. 15 E. of 3rd P.M.; Thence North along the East Boundary line of the State of Illinois to its intersection with the shore of Lake Michigan; Thence along said shore of Lake Michigan to its intersection with the Township line between Townships 37 and 38 North; Thence East to the West Boundary line of the State of Indiana; Thence North to the N.W. Corner of said State of Indiana; Thence East along the North Boundary line of said State of Indiana to its intersection with a line three miles distant from and parallel to the shore of Lake Michigan measured at right angles to said shore; Thence Northerly along said three mile line to a point opposite the Township line between T. 40 and 41 North; Thence West to the shore of Lake Michigan; Thence Northwesterly along said shore line of Lake Michigan to the place of Beginning.

Fig. 1.

bottom and 306 feet at water line. From Willow Springs to Lockport, fifteen miles, the channel is through rock, 160 feet at bottom and 162 feet at water line..

Above the Romeo curve the embankments are of earth from 6 to 8 feet in height, the spoil bank having a berm of about 50 feet in width.

From Romeo down to a point abput 1000 feet above controlling works the channel is cut in the solid rock, the elevation of top of same being practically constant at about elevation +5, thus requiring no concrete wall. At the point mentioned above controlling works the elevation of rock drops to about -6 and retaining walls are necessitated.

The walls on both sides of the channel from this point down to a point immediately below Butterfly Dam are of concrete reinforced by a back fill of rock from 50 to 80 feet in width on top.

At the controlling works there is a further and decided drop in the elevation of the surface of the rock and this drop originally determined the location of the controlling works.

At one time the plan of establishing the power plant at this point was under consideration, but after further investigation it was decided more feasible and practical to locate power plant some two miles farther down channel, thus attaining a nominal head of water of from 25 to 28 feet. By locating power house at this point the pondage basin could be enlarged to an area of 4,000,000 square feet. A depth of 5 feet of this is available in furnishing water to turbines.

Between the controlling works and the power house the east wall is of the same character as the walls above controlling

works. The west wall, however, is of different construction. The total amount of material to be excavated and spoiled at this point was insufficient to provide a bank fill of rock for both sides of channel and in consequence an earth embankment with concrete core wall was used on west side of channel. The excavated rock of good quality from the site of power house and from the main channel was crushed and used in all concrete work for the power house, the locks and dams, the core wall, side walls, and for concrete work at Butterfly Dam. Care was taken to separate and reserve all the suitable rock for this purpose.

The width of main channel is 160 feet with a nominal depth of 30 feet. The cut through the solid rock was made by a channeling machine.

Below the controlling works the elevation of the natural surface of the surrounding country, including the cities of Lockport and Joliet, is much below the surface of the channel. The elevation of the street at the court house in Joliet is about -40 feet, Chicago City Datum. The entire country shows an outcropping of rock with a very meager soil of clay and sand. The underlying rock varies from soft limestone to hard flinty limestone.

Fig. 2 shows to a larger scale the layout in the vicinity of the controlling works and Butterfly Dam. As is seen from this diagram the main channel widens out at the controlling works into a Windage Basin, some 400 feet wide, with the Bear Trap Dam along the west bank at the lower end of basin. By raising and lowering the dam, the direction and amount of flow in the main channel can be regulated. The elevation of top of dam is +5 feet when dam is raised to its highest point and elevation at lowest position is

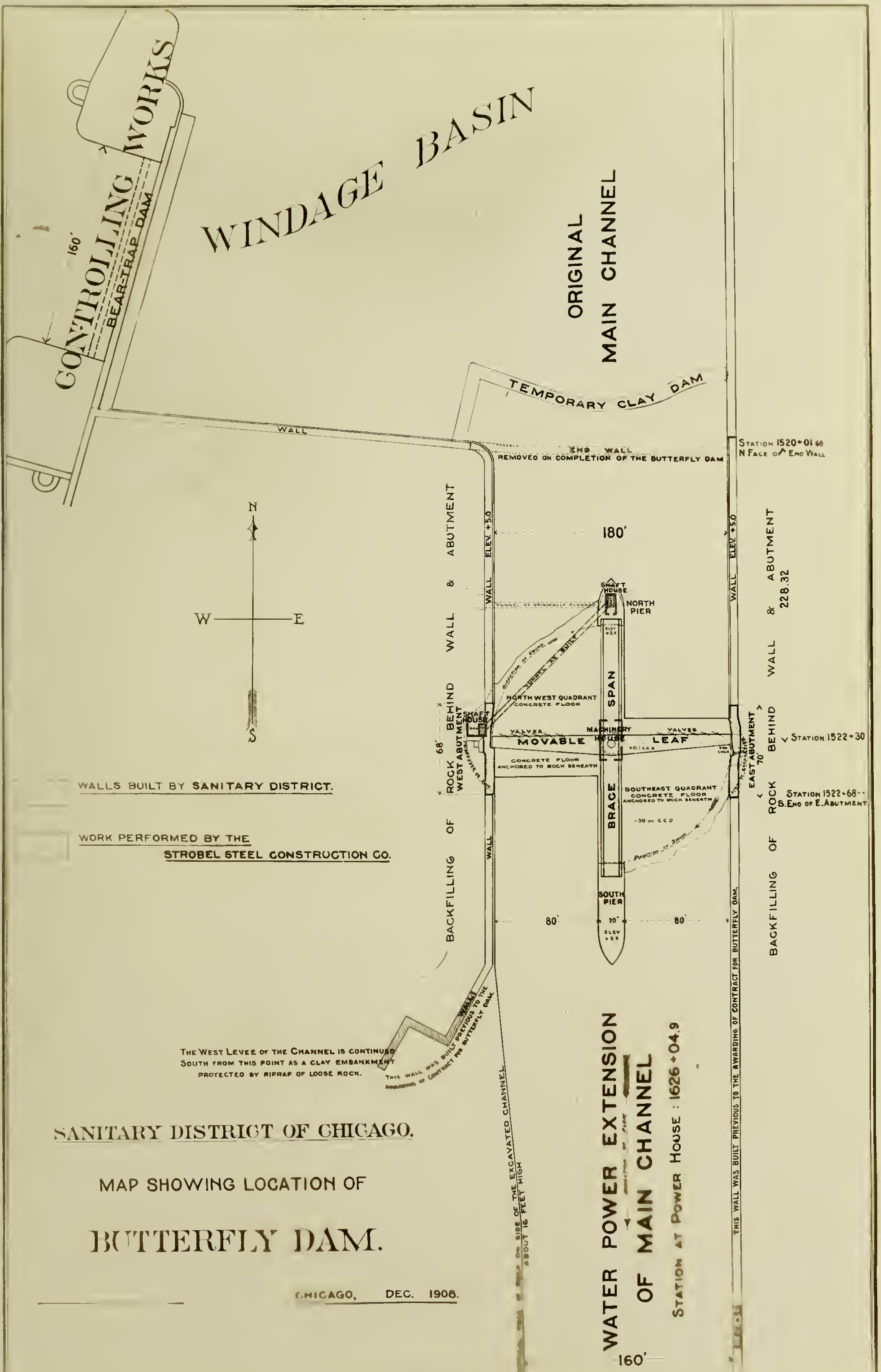

WINDAGE BASIN
CONTROLLING WORKS
BEAR-TRAP DAM
160'
ORIGINAL
MAIN CHANNEL
TEMPORARY CLAY DAM
WALL
END WALL
REMOVED ON COMPLETION OF THE BUTTERFLY DAM
STATION 1520+01.68
N FACE OF END WALL
N
W
E
S
180'
BACKFILLING OF ROCK BEHIND WALL & ABUTMENT
ELEV. +5.0
228.32
SHAFT HOUSE
NORTH PIER
SPAN
NORTH WEST QUADRANT
CONCRETE FLOOR
MACHINERY HOUSE
VALVES
MOVABLE LEAF
CONCRETE FLOOR
ANCHORED TO ROCK BENEATH
WEST ABUTMENT
68'
EAST ABUTMENT
70'
STATION 1522+30
SOUTHEAST QUADRANT
CONCRETE FLOOR
ANCHORED TO ROCK BENEATH
BRACE
STATION 1522+68
S. END OF E. ABUTMENT
SOUTH PIER
80'
20'
80'
WALLS BUILT BY SANITARY DISTRICT.
WORK PERFORMED BY THE
STROBEL STEEL CONSTRUCTION CO.
THE WEST LEVEE OF THE CHANNEL IS CONTINUED
SOUTH FROM THIS POINT AS A CLAY EMBANKMENT
PROTECTED BY RIPRAP OF LOOSE ROCK.
THIS WALL WAS BUILT PREVIOUS TO THE AWARDING OF CONTRACT FOR BUTTERFLY DAM.
ABOUT 16 FEET HIGH
WATER POWER EXTENSION
OF MAIN CHANNEL
STATION AT POWER HOUSE : 1626+04.9
160'
SANITARY DISTRICT OF CHICAGO.
MAP SHOWING LOCATION OF
BUTTERFLY DAM.
CHICAGO, DEC. 1908.

Fig. 2.

-12 feet, a range of 17 feet. The width of dam is 160 feet. The purpose of the enlargement of channel into windage basin is to provide a large enough quantity of water to make dam effective and to reduce drop of water at crest.

Above the Bear Trap Dam and on same side of channel are seven sluice gates, with provision made for a possible future installation of eight more. The sluice gates are provided to be used as auxillary to the Bear Trap Dam in case of necessity. The water passing over the dam and through the sluice gates is wasted into the old channel of the Desplaines River.

Before the Wat er Power Extension of main channel was projected, the south wall of Windage Basin extended across the present main channel as is shown in dotted lines. Above this extended end wall was built a Temporary Clay Dam to be used while the wall across main channel was being removed. Station number of north face of end wall is 1520+01.68.

It will be noted that the Emergency Butterfly Dam, subject of this thesis, is placed at the head of the Water Power Extension of the main channel, and that the walls on either side of latter at this point are backfilled with rock to a point about 400 feet below south wall of Windage Basin. At this point the concrete wall on west bank flares out and does not follow the rock channel cut. Concrete wall continues but a short distance and is joined by a clay embankment with rock slopes. This construction is on natural surface of rock which is at about elevation -12. At a point farther down channel where natural elevation of surface rock drops to about -16 or -18 the wall consists of a clay embankment protected by a riprap of loose rock with a con-

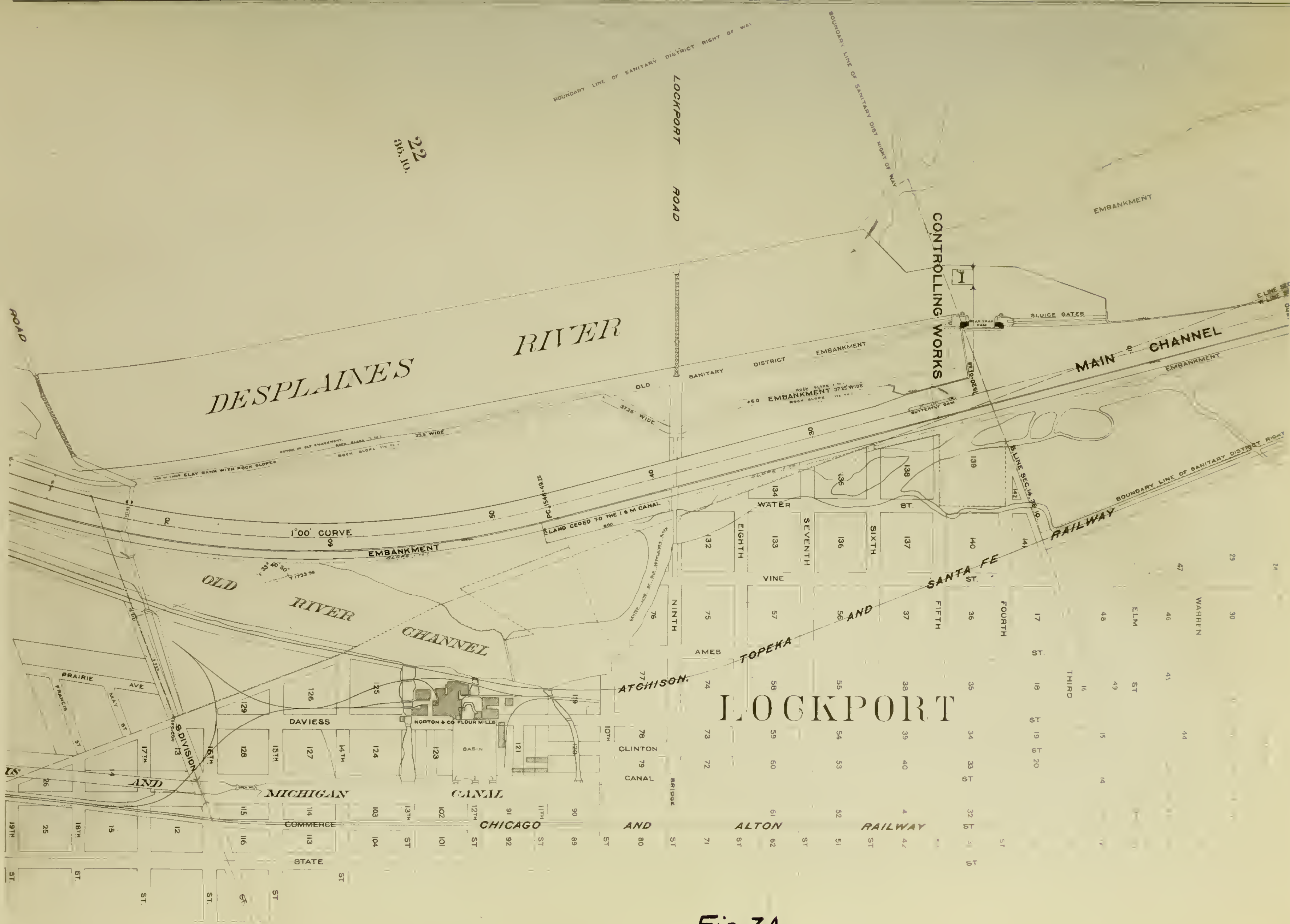

LOCKPORT
DESPLAINES RIVER
MAIN CHANNEL
CONTROLLING WORKS
SLUICE GATES
EMBANKMENT
OLD SANITARY DISTRICT EMBANKMENT
OLD RIVER CHANNEL
LOCKPORT ROAD
ROAD
BOUNDARY LINE OF SANITARY DISTRICT RIGHT OF WAY
ATCHISON, TOPEKA AND SANTA FE RAILWAY
CHICAGO AND ALTON RAILWAY
MICHIGAN AND CANAL
NORTON & CO FLOUR MILLS
LAND CEDED TO THE I & M CANAL
1°00' CURVE
S DIVISION
22
36.10.
WATER
VINE
AMES
CLINTON
CANAL
COMMERCE
STATE
DAVIESS
PRAIRIE
AVE
MAY
FRANCIS
WARREN
ELM
THIRD
FOURTH
FIFTH
SIXTH
SEVENTH
EIGHTH
NINTH
BRIDGE
BASIN

Fig 3A.

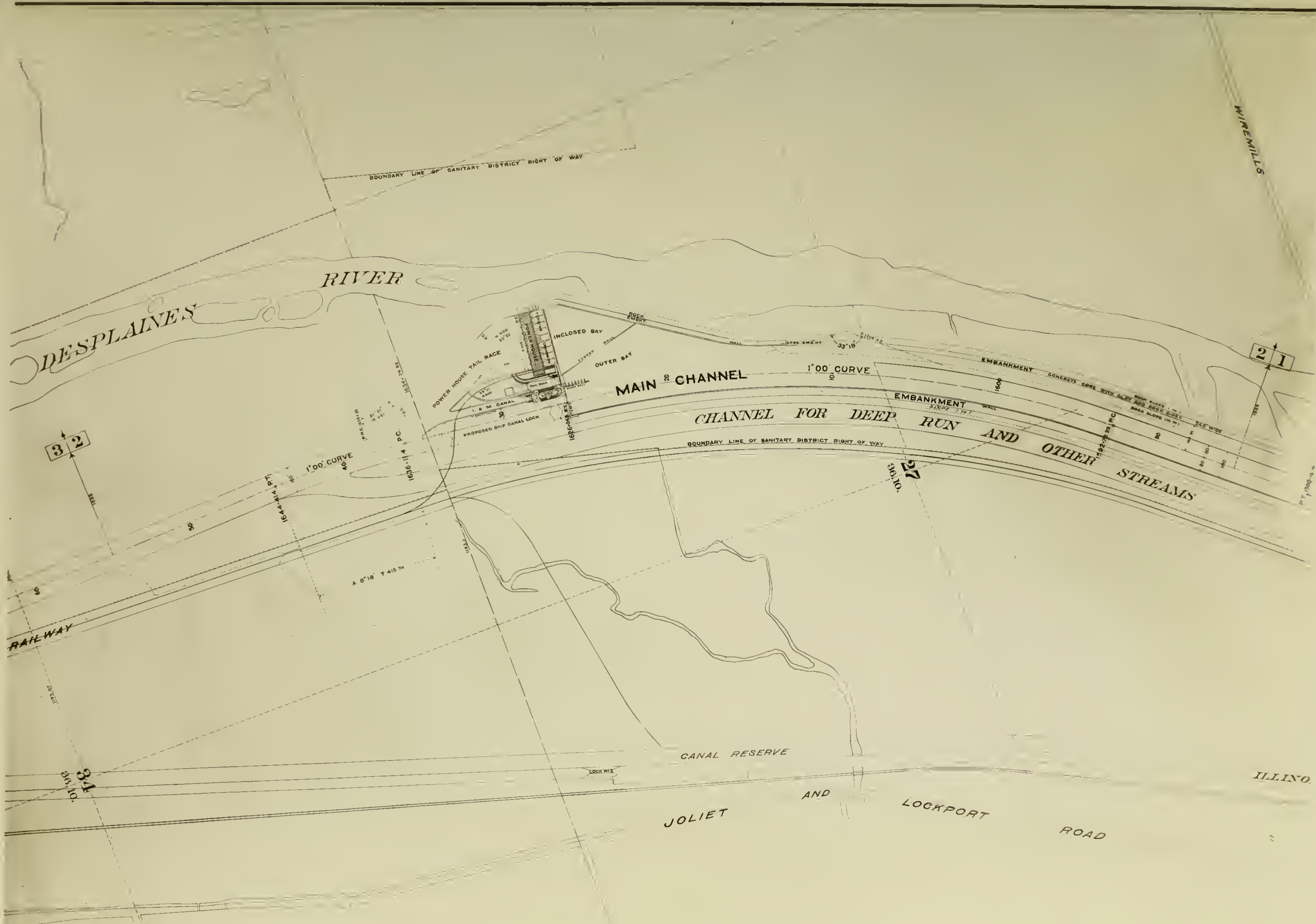

WIREMILLS
BOUNDARY LINE OF SANITARY DISTRICT RIGHT OF WAY
DESPLAINES RIVER
POWER HOUSE
INCLOSED BAY
OUTER BAY
POWER HOUSE TAIL RACE
PROPOSED SHIP CANAL LOCK
MAIN CHANNEL
1°00' CURVE
EMBANKMENT
CHANNEL FOR DEEP RUN AND OTHER STREAMS
BOUNDARY LINE OF SANITARY DISTRICT RIGHT OF WAY
27
36.10.
34
36.10.
RAILWAY
CANAL RESERVE
JOLIET AND LOCKPORT ROAD
ILLINO

Fig. 3B.

crete core wall. For extent and further location of these walls and also for relative locations of power house, Illinois and Michigan canal lock, proposed ship canal lock, see Figs. 3A and 3B.

The southerly end of the head race of the water power extension or the pondage basin referred to previously is closed, commencing on the east, by the following structures: A gravity wall, an end view of which is shown in Fig. 4; a lock for the I. and M. canal; a sector dropgate with 17 foot lift and 48 foot waterway for regulating the height of the water in the basin; a sector dropgate 12 feet wide for discharging floating debris that may collect in the inner bay in front of the power house, and the power house itself, 385 feet long. Built at an angle across the channel is an arched concrete fender wall which diverts the ice to the controlling dam.

The power house was designed and constructed for the installation of eight generators of 4000 kilowatts each, and three exciter units of 350 kilowatts each, to be direct connected to horizontal waterwheel units of 6000 horse power each in case of generators and of 600 horse power each for the exciters. The allowable discharge of water is 300,000 cubic feet per minute, the canal being of sufficient section to allow a possible future flow of 500,000 cubic feet per minute.

Fig. 4.

End view of gravity wall at south end of head bay, power house.

II.

NECESSITY, USE AND NOVELTY OF THE EMERGENCY BUTTERFLY DAM.

It was noted in I that the elevation of the city of Joliet was far below that of the water surface maintained in the pondage area, and conditions called for the construction described as the most suitable, i.e., the east embankment a concrete wall with backfill of rock, while the west embankment consisted of an earth fill with concrete core wall, riprapped.

The stability of this earth wall has been questioned and the doubt arose in the minds of many as to its absolute safety. (See Journal of Western Society of Engineers of date August 1907, p. 514, paper presented by Mr. Isham Randolph, Chief Engineer).

The channel above the controlling works, as was stated in I, has concrete walls with heavy rock back fill which precludes any possibility of a sudden or dangerous break from any cause whatever through these walls. The water power extension of channel from controlling works to power house should also have the same degree of safety as the channel above. With these in mind, the chief engineer decided there should be placed in the new channel near the controlling works a dam which could be quickly closed- thus in an emergency shutting off the flow of water into the weaker portion of channel, and preventing possible flooding of the surrounding country. Thus we have the name - The Emergency

Butterfly Dam. Hereafter, for brevity, the term Butterfly Dam will be used.

As to further uses of this dam, when Butterfly Dam is closed the water can be diverted over the Bear Trap Dam in the same manner as before water power extention was built. In this manner, when large masses of floating ice are passing down channel, they can be disposed of over the Bear Trap Dam. Also, in placing new units at the power house and at other times when it is of advantage to lower water in pondage basin 5 or 6 feet, all that it is necessary to do is to close Butterfly Dam and lower the sector dams at power house until water is brought down to desired elevation. This has been done a number of times.

We have discussed briefly the reasons for building Butterfly Dam - why it was located at its present site, and some of the minor uses to which it may be put. We shall now endeavor to show why the unique design was used.

When the original project of the drainage canal was under discussion, the question of controlling the water in the main channel and Chicago River arose, and also as to the advisability of placing the controlling works at Lockport, the lower end of the canal, or at a site not far from the head at Robey Street. At this time, as stated in the Journal of the Western Society of Engineers, of February 1901, Mr. Ossian Guthrie proposed a controlling dam which possesses certain characteristics of design later used for the Butterfly Dam. (See Fig. 5.) Mr. Guthrie's idea was to use two "lockgates" located symmetrically with respect to center line of channel which gates when swung at right angles to channel would completely close same. The gates were to be pivoted

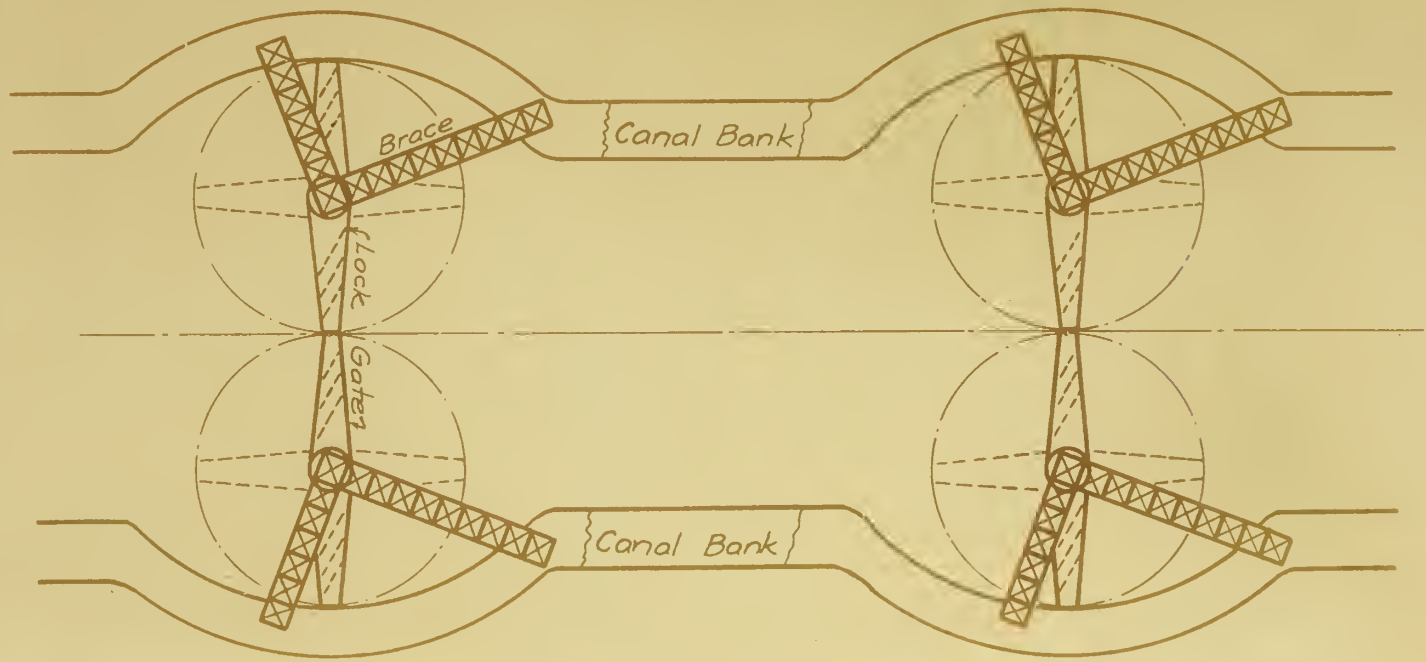


Fig. 5.

Plan for Controlling Flow
through
The Chicago Sanitary and Ship Canal.
Proposed by Ossian Guthrie.

Journal W.S.E. Feb. 1901.

at their respective centers, lower pivot being buried in floor of channel, and upper pivot being held in position by two diagonal struts which tied same to the abutment walls.

Later, in connection with the Water Power Extension, Mr. Isham Randolph, Chief Engineer, suggested the use of a butterfly valve design for a dam with a vertical pivot and a movable leaf swinging on same. From this idea was evolved the present structure.

The site and uses to which the canal was to be put necessitated an entirely clear channel when dam was not in use, and precluded the employment of a wicker or other dam which would obstruct the channel at all times.

The swing bridge dam could not be used either. This dam is designed after the fashion of a swing bridge on a center pier, with movable wickers and sliding shutters. The time of operation, however, is too long, and the cost also would have been greater, with greater complexity of control, and in case of emergency, speed and simplicity are most important factors.

The site, hewn out of solid rock, lent itself admirably to masonry and stone foundations capable of sustaining great loads and fixed position. It would not be advisable to construct a butterfly dam at a location where rock foundations were not obtainable, as the complete success of the design of the structure depends upon the maintaining of the two pivot shafts in perfect alignment.

The idea as worked out and the design as made have never been used elsewhere, to the best knowledge of all concerned, nor has a similar scheme ever been suggested for any like use.

Fig. 6.

In this view is shown the down stream pier, the leaf in open position, the west wall as it diverges from the channel cut and the natural surface of the rock.

Fig. 7.

This view shows the upstream pier, the upstream face of leaf in closed position, the side walls, the brace span, the floor of channel with granolithic surfacing. The channel cut and foot of concrete wall can be seen.

Fig. 8.

This view shows upstream pier and down stream face of leaf in open position beneath brace span. The narrowing of channel cut from 180 feet at dam to 160 feet below dam is clearly indicated.

Fig. 9.

A view looking directly upstream showing leaf in closed position.

III.

GENERAL DESCRIPTION OF THE BUTTERFLY DAM AND ITS METHOD OF OPERATION.

The Butterfly Dam consists of a movable leaf or dam proper which can be swung about a vertical pivot at its center, either into position squarely across channel or parallel with direction of flow, allowing a clear and unobstructed passageway on either side. A bracespan lengthwise of channel supports upper pivot, while lower pivot is anchored in the solid rock floor. Figs. 6,7, 8 and 9 show general ideas of design, with descriptions appended.

The movable leaf consists of seven horizontal girders which support the sheathing plates on the up stream side and are braced on the down stream side by two sets of diagonal bracing.

Each arm of movable leaf is divided into ten panels, at each panel point of which is a brace frame or solid diaphragm which ties the seven girders rigidly together from top to bottom of dam. Heavier end girders at both extremities aid the above in preventing unequal deflection of girders and consequent warping of dam. See Figs. 10, 11 and 12.

At center of movable leaf is center box girder which is composed of four webs, two of which about 13 feet centers are in the top (upstream) and bottom (downstream) flanges of girders. The two other webs are about 7 feet centers, this being the center

Fig. 10.

Five of the seven horizontal girders are shown in position in this view. The center box girder to which remaining trusses are to be rivetted is clearly seen above the girders, together with upper center pivot. At far end can be seen the vertical end girders which tie horizontal ones together. It will be noted that the vertical diaphragms between the four lower girders have solid webs while those above are open brace frames.

Fig. 11.

Up stream pier, movable leaf down stream side before bracing was erected. Above the up stream pier projects upper portion of rocker arm and from down stream pier top of skew-back.

Fig. 12.

Down stream face of east half and lock end of movable leaf with the double system of bracing complete. The floor of channel which is the southeast quadrant shown in view has a granolithic surface. Operating pinion and rack are seen above center box girder.

panel of leaf span. At the top and bottom of center box girder are the upper and lower pivots respectively.

The span of girders is 184 feet with a depth at center of 13 feet and 3/4" and of 7 feet and 4" at ends.

They are spaced 4 feet apart at bottom and 5 feet 6" apart at top as is shown in Fig. 42. This figure shows, also, the upper pivot as it is carried by center box girder and the diaphragms in the plane of each of the horizontal girders. It shows further the heavier pivot bearing diaphragms at top and bottom. See Fig. 13.

In the plane of the sheathing side of the dam are twelve openings; six on either side of center, in each of which openings is placed a butterfly valve on a vertical 4" shaft. This shaft extends to the top of the dam where is mounted a worm gear which is driven by a motor through a line shaft by proper reduction. The valves on either side of center pivot are under separate control. At the top of vertical shaft is a cam which operates a trip and clutch preventing the machinery from being jammed after valve has been completely open or shut. See Figs. 14, 15, 16, and 17.

The valve is composed of a cast steel form upon which two steel plates are rivetted. The valve openings are four feet by six feet and are located between horizontal girders 4 and 5, the upper edge of the opening being 12 feet 6 inches below datum.

The primary object of the valves was to fill up the channel below the dam. It was also proposed to use the valves as an assistance in operating the dam, but it has always been possible to operate the dam by means of the machinery provided. It is readily seen that by opening the valves on one side and by leav-

Fig. 13.

Center box girder on board cars in shop. The lower end of girder is in foreground. The position of cross girders which carry dead load of leaf to center pivot is clearly indicated by rivet heads just above hole for pivot.

Fig. 14.

Up stream face of one half of movable leaf showing six small butterfly valves in closed position. It will be noted that floor of channel in foreground, which is northwest quadrant, has a granolithic surface.

Fig. 15.

Operating machinery for valves shown in Fig. 13. In the foreground is a Northern 7 1/2 H.P. motor geared to the line shaft. An indicator is mounted above the vertical shaft of one valve to show position of valve.

Fig. 16.

Detail view of line shaft, jaw clutch and gear reduction of one valve.

Fig. 17.

Automatic trip release which is operated by a cam on vertical valve shaft.

ing them closed on the other side there would exist an unequal pressure on the two arms of leaf equal approximately to the pressure of the moving water upon the area of the valves opened. It was found that when there was a difference of head of about two feet on the two sides of dam and with the valves closed on the east half, the pressure was sufficient to start the dam in motion.

The lower pivot is supported in a square box girder with heavy diaphragms top and bottom which receive the horizontal thrust. The vertical load is carried from center box girder of movable leaf to lower pivot support on a pivot bearing consisting of a cast steel base resting on a spherical bronze disc, which in turn rests on top of pivot. This pivot carries entire weight of movable leaf in addition to over 70% of the horizontal thrust from dam. Fig. 39 is a detail drawing of lower pivot with base casting and loading disc and casting. This figure also shows bearing diaframs of center and lower box girders.

Fig. 40 shows detail of lower pivot support.

Fig. 38 is a general assembled drawing.

See also Figs. 18, 19, 20, 21 and 22.

The lower pivot shaft is prevented from turning by inserting a six foot length of 2 1/2 inch cold rolled shafting and by looping reinforcing rods around same, it is securely anchored in concrete. The hole through pivot shaft facilitated handling of same by inserting short shaft with a hitch around same.

The lower pivot is supported by a cast steel base on a reinforced concrete footing on the solid rock. The horizontal load from dam is transmitted to pivot and in turn through the box girder to a horizontal girder and a vertical grillage with an area

Fig. 18.

Lower pivot support box girder as unloaded from car.

Fig. 19.

Holes in top and bottom diaphragms

for lower pivot shaft of lower box girder.

Fig. 20.

Anchorage columns projecting above rock are in foreground. In background is skip car which has just dumped its load of concrete into pit.

Fig. 21.

Anchorage columns in foreground. The lower box girder is supported on cribbing ready to be lowered into place. In background is vertical grillage and horizontal cross girder. In center is center pivot projecting above lower box girder.

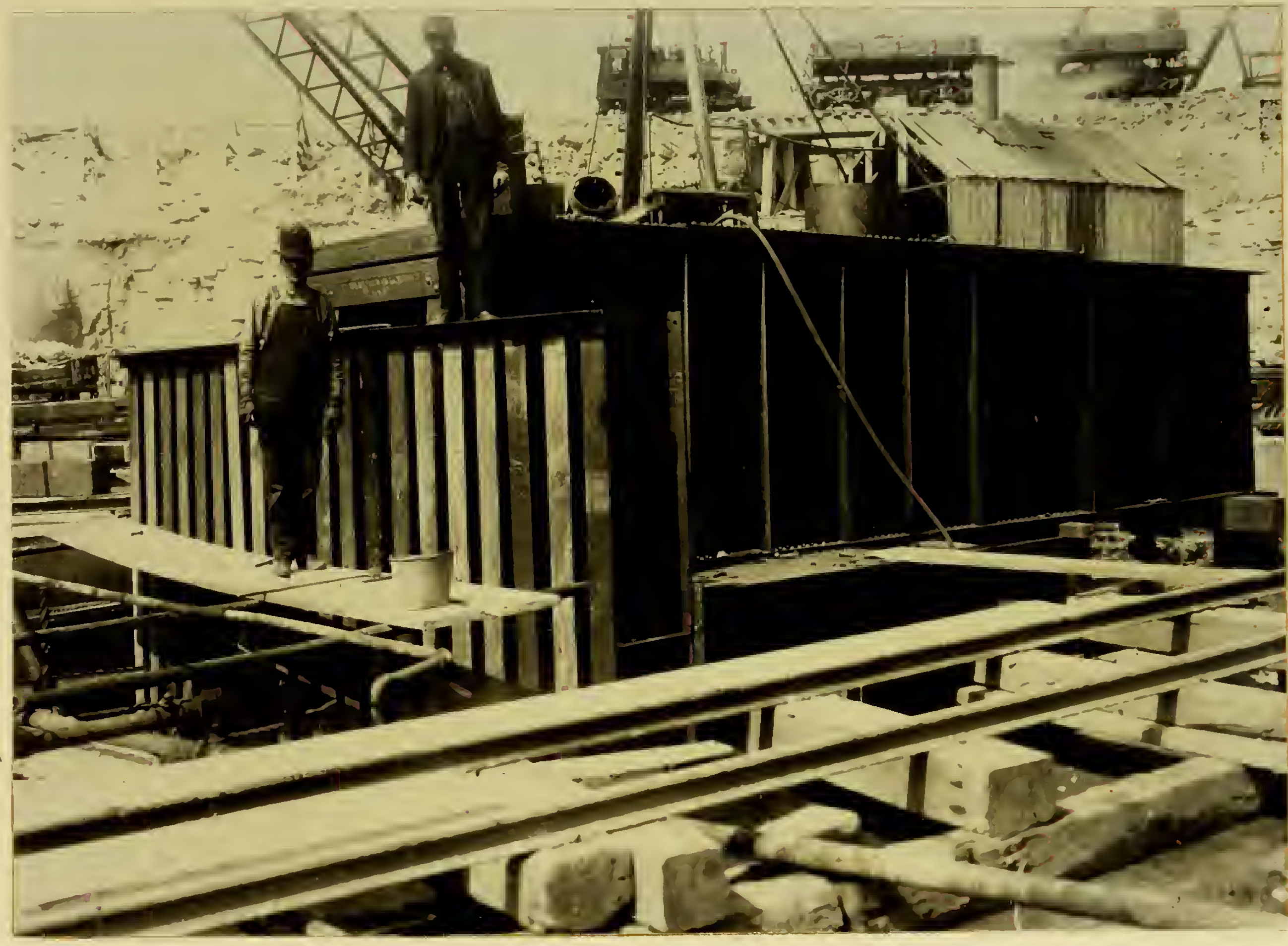


Fig. 22.

Vertical grillage in foreground, with lower box girder and pivot from opp. end to that shown in Fig. 20.

10 feet by 20 feet and to a vertical anchorage imbedded in concrete 40 feet below floor of channel. The pit for entire anchorage including box girder, was excavated in solid rock. Pivot and anchorage were then buried in concrete, great care being taken to leave no voids.

The upper pivot is supported and anchored to center box girder. The upper end of pivot has its bearing in a horizontal diaphragm in plane of bottom chord of brace span. To this diaphragm is transmitted the pressure from dam.

The bearing in this diaphragm is a cast steel ring forced into place and is lined with a bronze ring. The upper pivot is shown in place in center box girder in Fig. 42.

The brace span is primarily a twin column. At the center pivot is a diaphragm from which the load is received and carried through columns to the down stream pier, where there is a skew back and anchorage. See Fig. 38.

The skew back consists of a cross box girder joining two short columns which connect to end gusset plate of brace span. The load from cross girder is distributed to an I beam grillage. To the end gusset plates, also, is a vertical anchorage which extends through entire depth of pier and into rock floor of channel some 8 feet. See Figs. 23, 24, 25, 26, 27 and 28.

The twin column is supported by a Petit truss of 202 foot span and also acts as the bottom chord of same. The trusses are spaced 14 feet centers, are twenty feet deep at center and 16 feet deep at hip. In plane of bottom chord heavy bracing was used in order to prevent any undue lateral distortion of truss, and to be capable, also, of receiving a heavy lateral blow from passing vessels or barges.

Fig. 23.

Skew back and grillage in position in south pier before forms were finished and concrete placed.

Fig. 24.

Down stream pier vertical anchorage during erection.

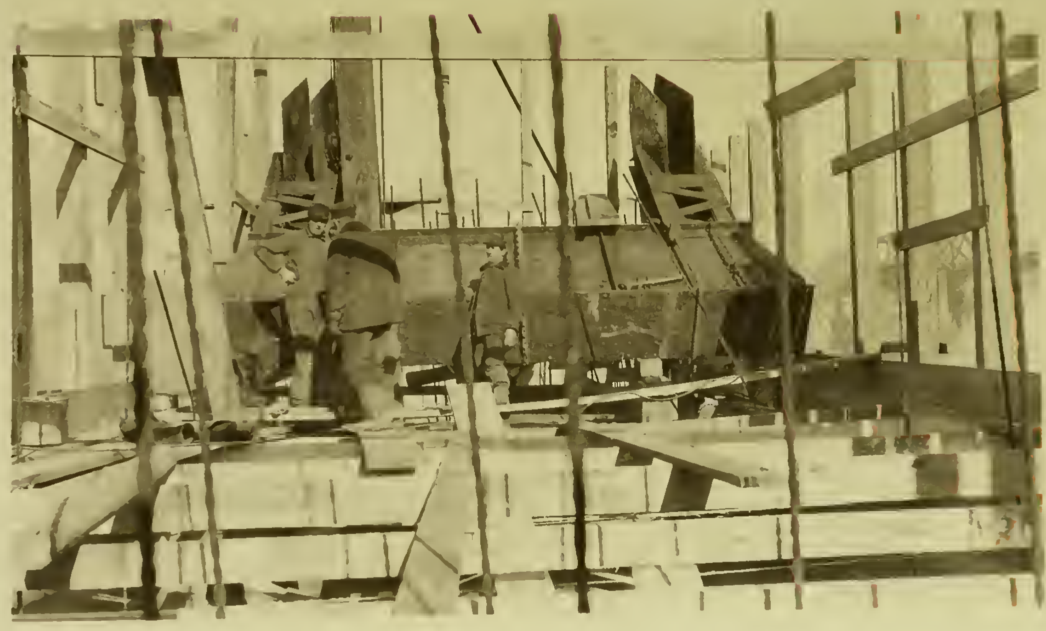


Fig. 25.

Skew back and box girder before grillage was placed. Reinforcing bars are shown projecting above forms.

Fig. 26.

Vertical anchorage of skew back of south pier in position. Also reinforcing rods projecting from concrete finished to floor of channel.

Fig. 27.

Vertical anchorage in place. Forms for pier under construction. Reinforcing rods are clearly shown.

Fig. 28.

Completed down stream pier. Controlling works in distance.

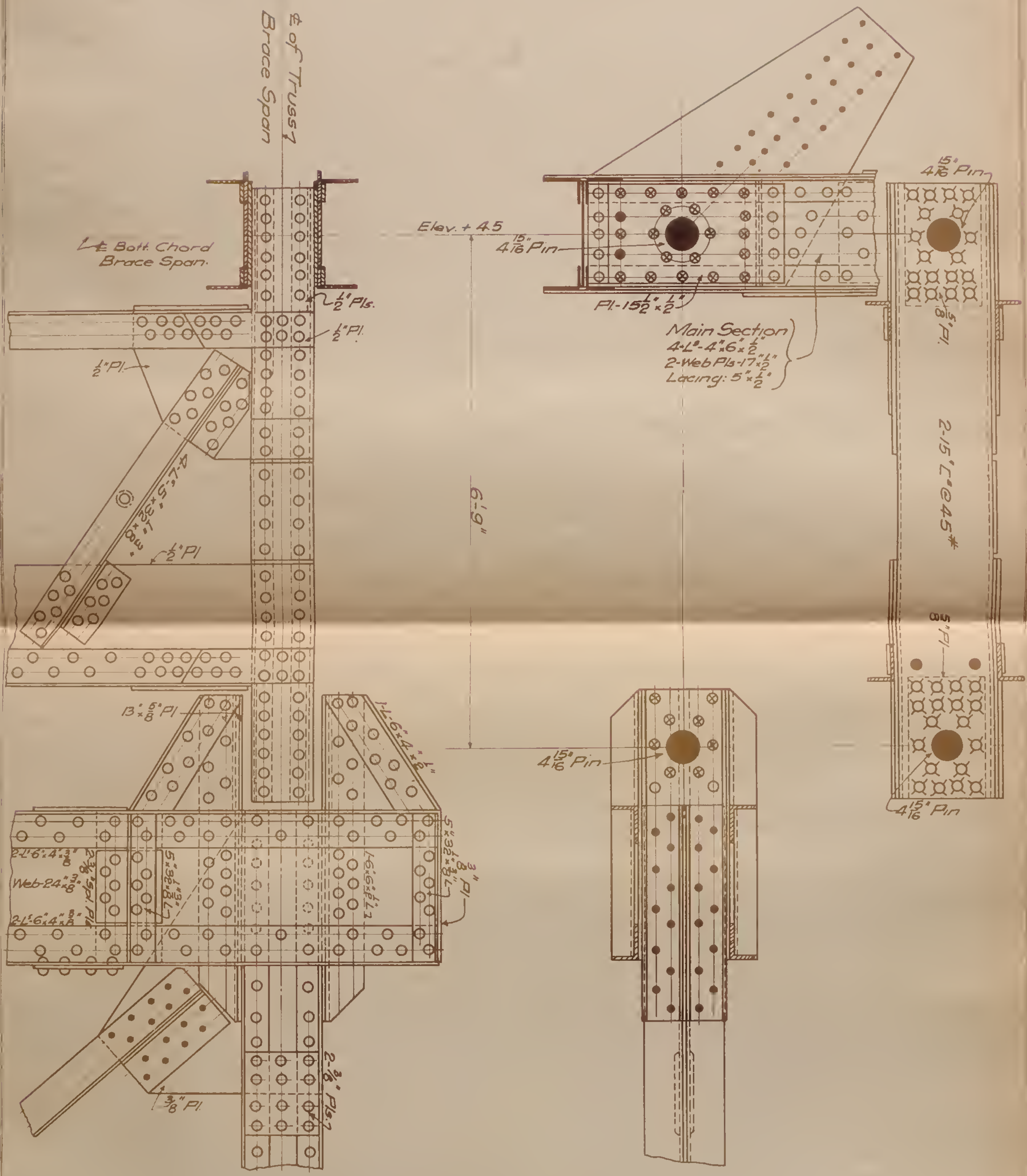
The up-stream end of truss is supported on a rocker arm which in turn is carried by a braced steel frame in up stream pier. This rocker arm allows for a longitudinal motion and in addition to this is capable of resisting a horizontal thrust of 250,000 pounds.

Fig. 29 shows a detail of the rocker arm in position.

The center diaphragm of brace span is reinforced by means of longitudinal and cross girders, which also form the support for the machinery and the entire center portion of truss is enclosed, forming operator's house.

The down stream pier receives its load from the skewback which is a continuation of the twin columns of the brace span. The skewback is set at an angle of 30°, is entirely embedded in the pier, and distributes its load over an I beam grillage. The uplift, due to the thrust on skewback, is carried by the vertical anchorage. In order to bind the underlying strata of rock together, and to dowel the pier to floor of channel reinforcing bars were freely used, placed in holes drilled well into the solid rock. The pier was reinforced throughout for expansion stresses, with additional reinforcement along the lines of greatest stress. The pier is 20 feet wide, 80 feet long and 34 feet high. Clear width of channel either side of pier is 80 feet. The main mass of concrete in pier is 1:3:6 respectively cement, screenings and broken stone, but in areas subject to higher pressure the mixture, being 1:2 1/2:4 1/2 respectively cement, sand or limestone screenings and broken stone; and the up-stream pier carries the expansion end of brace span by means of the rocker arm and anchorage, which latter extends down to floor of channel. This pier forms the shaft and carries the shaft house for the tunnel. This pier, also, is

Fig. 29.



Detail of Rocker Arm
UpStream Anchorage

reinforced for expansion. It is 20 feet wide, 40 feet long and 34 feet high, and is made of a I:3:6 concrete. A row of I beams securely anchored in the pier projects about 18 inches from back of pier and prevents movable leaf from passing beyond central position up and down stream.

An iron stairway leads down shaft in up stream pier to tunnel which crosses underneath channel diagonally to center of west abutment. The tunnel is a large trough in the rock floor of channel with walls, floor and roof of concrete. A richer mixture 6 inches thick, is used as a waterproof lining. Tunnel opening is 4 feet by 7 feet and is about 135 feet long.

The abutments which form a part of walls of channel receive their loads from ends of movable leaf. The west abutment receives its load direct upon horizontal beams reinforced by vertical I beams to distribute same. All is embedded in the concrete which is a 1:2 1/2;4 1/2 mixture.

The concrete was more securely anchored to rock by reinforcing rods placed in holes drilled and grouted into same.

This abutment contains the shore shaft of tunnel. A motor driven pump raises water from sump at west end of tunnel. Lead covered cables run from shore through tunnel and along brace span to operating motors. In addition to this use the principal use of tunnel is as passageway for operator.

While movable leaf is acting as entirely continuous or as continuous with supports uneven, in addition to support at center, the horizontal girders have direct bearing on west abutment and bearing through an end lock at east abutment. This end lock is composed of seven struts, one for each of the horizontal girders of movable leaf. See Figs. 30, 31, and 32. These struts are

Fig. 30.

Down stream face of movable leaf at east end with lock in closed position. Operating lever is shown at top but winch had not yet been installed.

Fig. 31.

In the foreground is seen head of operating lever of end lock; also two bearings of end lock.

Fig. 32.

Operating winch for releasing end lock. Lock is swung into closed position and held by counterweight.

securely braced together by I beam and plate diaphragms, and are held in position and are swung on a vertical shaft mounted at end of leaf. The vertical shaft is supported in bearings which carry the dead weight of lock. The shaft end of each of these struts is composed of a casting rounded to take bearing against a bronze lining in shaft box, transmitting the load direct from strut to girder without taking the load through the shaft at all. The lock is opened by means of a winch and cable and closed by means of a counterweight. The end shoes of struts of lock bear upon cast steel bearings which are supported on horizontal and vertical I beam grillage, embedded in the east abutment. See Fig. 33.

The concrete in east abutment is of same quality as that of west abutment, and is anchored to surrounding rock by vertical and slanting reinforcing rods in same manner.

The entire portion of floor of channel which is traversed by the movable leaf was excavated from 2 to 4 feet, with the entire width of channel at and just below the leaf, and concrete floor was securely dowelled to rock. The object of this was not only to tie the concrete to the rock, but also to bind together the several layers of rock in floor of channel which lay in distinct strata from 10 to 24 inches in thickness. The entire floor of channel was surfaced, brought up to grade and finished off with a granolithic surface consisting of one part Portland cement and two parts coarse screened and washed sand. The elevation of floor was made about one inch below movable leaf at center pivot, sloping off to about three inches below same near ends.

The main operating machinery of the dam consists of two complete sets driven by two independent motors, which by proper gear

Fig. 33.

Steel in east abutment during erection. Cast steel shoes upon which end lock has bearing are not in place.

reduction actuate two pinions. These pinions engage sections of a circular rack 15 feet in diameter, which is mounted on upper end of center box girder of movable leaf. For machinery diagram see Fig. 47.

The machinery was designed to be run by two 20 H.P. motors but in ordering it was found difficult to secure these, and the next size larger, 30 H.P., were installed. These motors were controlled by a series-parallel controller, the first notches being in series, and the remainder in parallel. This method of operation was found unsatisfactory, as one motor or the other took more than its share of current in starting, producing undue strains in one set of machinery. The series-parrallel controller was removed and a parallel controller of special type was installed together with additional resistance. Now the two sets work together quite smoothly and uniformly, while with the series control each set operated at intervals until the machinery attained a fairly uniform speed. See Figs. 34, 35, 36 and 37.

Fig. 34.

General view of machinery. It will be noted that in this view pinion on vertical shaft on far set of machinery was not in position.

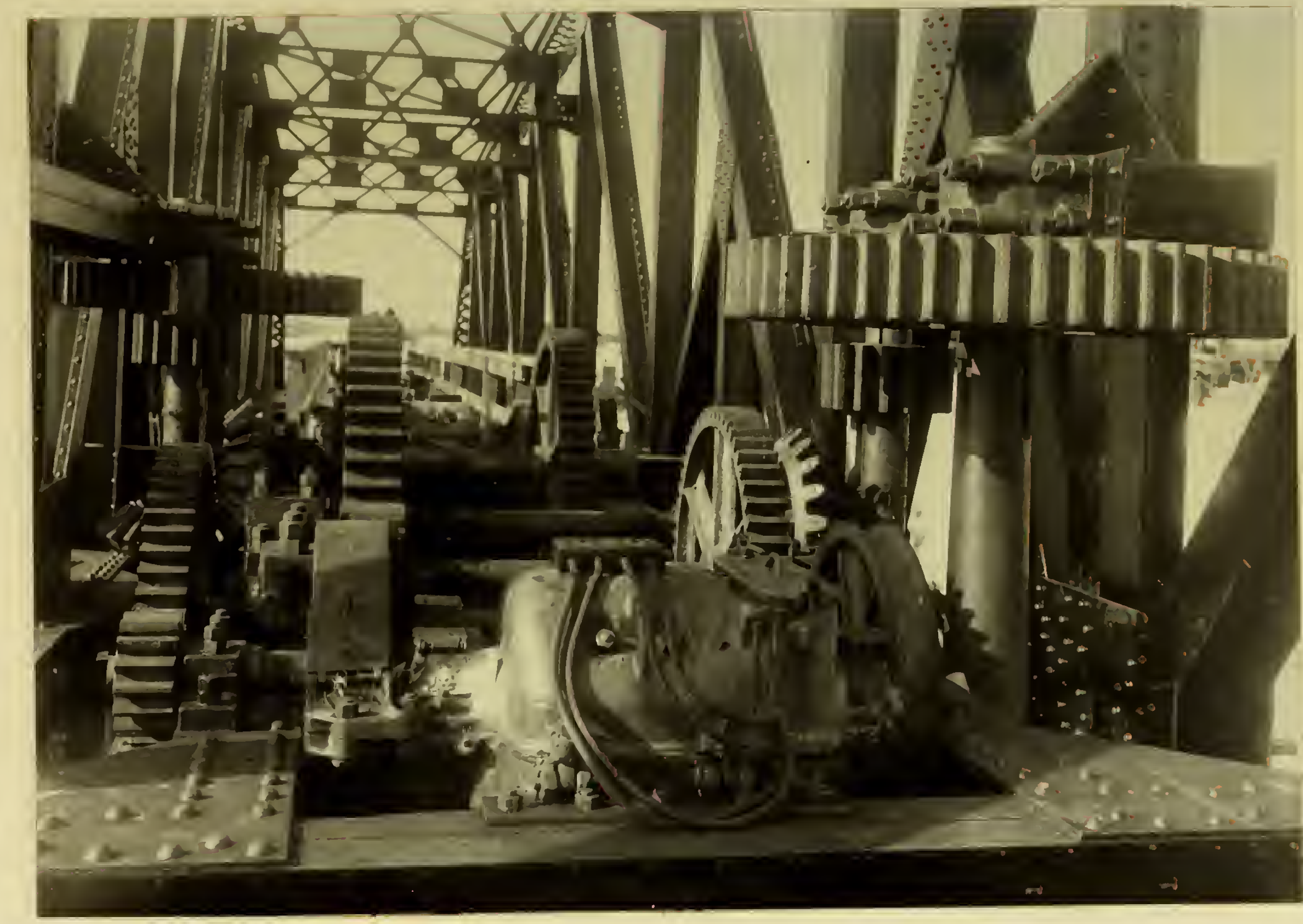


Fig. 35.

General view of machinery. Motor in foreground.

Pinions of vertical bevel gear shaft not in position.

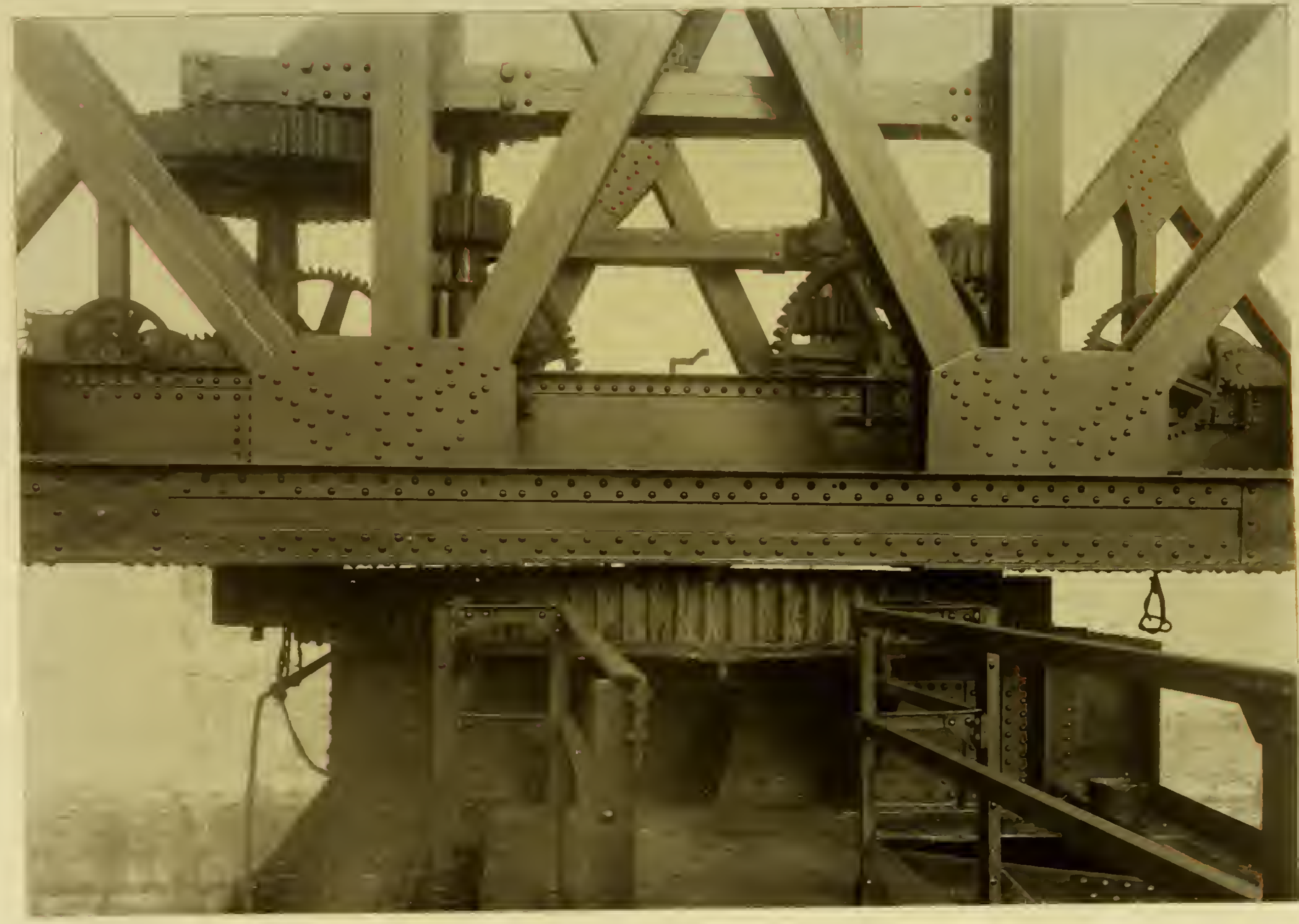


Fig. 36.

Side elevation of machinery. Pinion and rack can be seen distinctly below brace span.

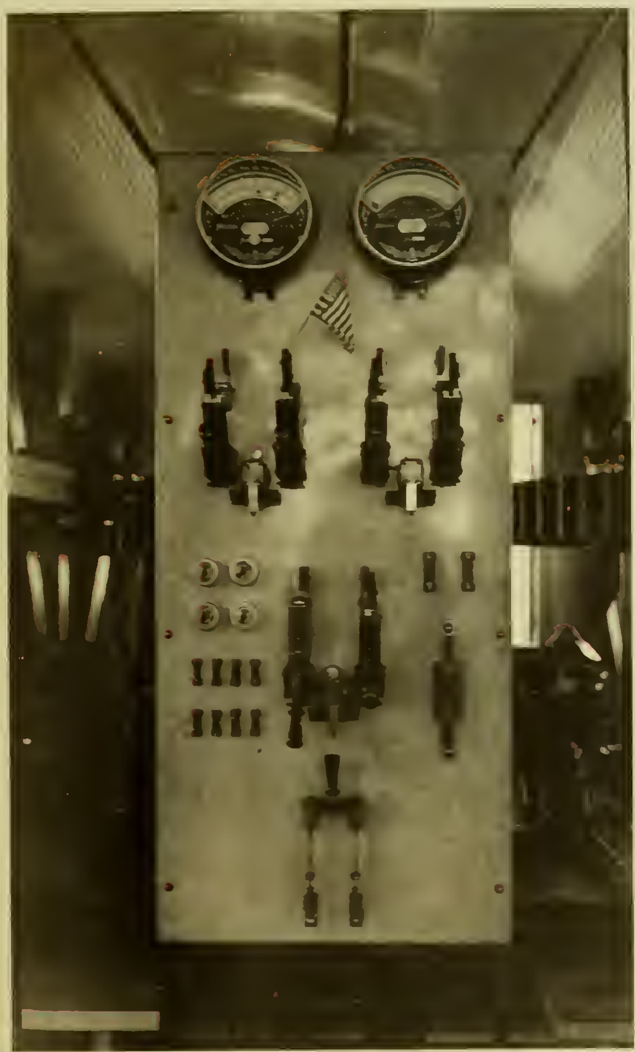


Fig. 37.

Switchboard, Voltmeter and Ammeter mounted at top, circuit breaker, switches and fuses are shown mounted on board.

IV.

METHOD OF LOADING - ASSUMPTIONS.

The stresses in the horizontal girders of the movable leaf were computed for three cases, viz., (a) cantilever, (b) continuous with even supports, (c) cantilever with a deflection of one inch at either end.

As built, the pivot at center is so located that movable leaf stands about two inches in front of end bearings, which would allow for two inches deflection in either arm. Under full load, and assuming no end reactions, the deflections varied from 0.66 inches in number 7 to 5.79 inches in number 2. In these calculations, however, only a narrow strip of sheathing plate was considered as section, and it was impossible to take into account the effect of the diaphragms, cross bracing and bracing on down stream side. The girders through the diaphragms tend to distribute the load amongst themselves, producing an average deflection, increasing the stresses in some of the girders and decreasing them in others.

The dam has never been loaded as a cantilever, and may never be, but it is very probable, taking into account the effect of the elements above, that should strict cantilever action ever occur, the deflection would be greater than two inches. Hence when dam is closed, horizontal girders could not act as entirely cantilever, but rather as continuous with supports uneven.

It was necessary to place center pivot so that movable leaf stood ahead of end bearings for two reasons - first, to allow for shortening of brace span due to compression caused by dam pressure, and second, to facilitate operation of lock by reducing to zero the pressure on same, when the water elevations on two sides of dam are equal or nearly so.

When dam is to be opened, valves are first operated and water pressure equalized, hence we do not have leaf acting as cantilever during opening, except for resistance offered by water due to motion of dam, but this is a very small load compared with full head of water.

The maximum pressure yet sustained by dam was the initial load when mud dam shown in Fig. 2 was torn out and water emptied into channel above the dam. At this time a three inch timber block was placed at west abutment, which left an opening of less than one-half inch. This play with the compression of block and shortening of brace span allowed for a deflection of about one-half inch at either end.

We may conclude, therefore, that the maximum stresses yet sustained by structure lie between those obtained by considering same as a cantilever with a deflection of one inch at either end and as a continuous girder with supports even.

The bracing on down stream side of leaf, together with the sheathing plates as web and the horizontal girders as flanges, supports the dead weight of the movable leaf. Actual weights were used and the distribution between the two systems was made according to same.

The leaf was cambered vertically 1 7/8 in. on up stream side, and 2 1/4 in. on down stream side with satisfactory results in

actual construction.

The brace span was designed to carry its own dead weight, a horizontal thrust of 250,000 pounds applied at any point along the length of bottom chord, and the portion of the pressure of water transmitted through the upper pivot to the down stream pier through the brace span as a column.

High unit stresses were used on account of the extreme improbability of the structure even being loaded as a cantilever and because of the only occasional partial loading even as a continuous span. The original test load is the most severe that could happen to the dam, but as stated before, only one-half inch deflection was allowed at either end.

It was necessary at the time the dam was built to remove the wall and underlying rock which separated the new water power extension from the old channel at the controlling works as shown in Fig. 2 referred to previously. The mud dam there constructed was not of sufficient stability to long retain its position and before the channel below Butterfly Dam, i.e. at the power house, was entirely completed ready to receive the water, it became necessary to close Butterfly Dam.

Pipe was placed along the bottom of movable leaf in front and at ends. Pipe 4 inches to 6 inches in diameter was used in sections, to which were attached 1/2 inch cables for removing same. On August 27, 1907 mud dam was cut and water was allowed to fill up to level of old channel at bear trap dam. The water stood at this elevation for several days before valves were opened to fill channel below Butterfly Dam. The leakage from dam amounted to a very small amount, wetting bed of channel below not much more than a heavy rain.

Operating machinery was designed to take care of the following:-

1. Acceleration of dead weight of dam, rotating friction on lower pivot support, and possible friction on side bearings due to unbalanced leaf.

2. Impulse of water against dam due to motion of same.

3. Unequal pressure against dam due to currents along face and around ends of dam.

4. Possible assistance of valves by opening same on advancing side and closing them on retreating side.

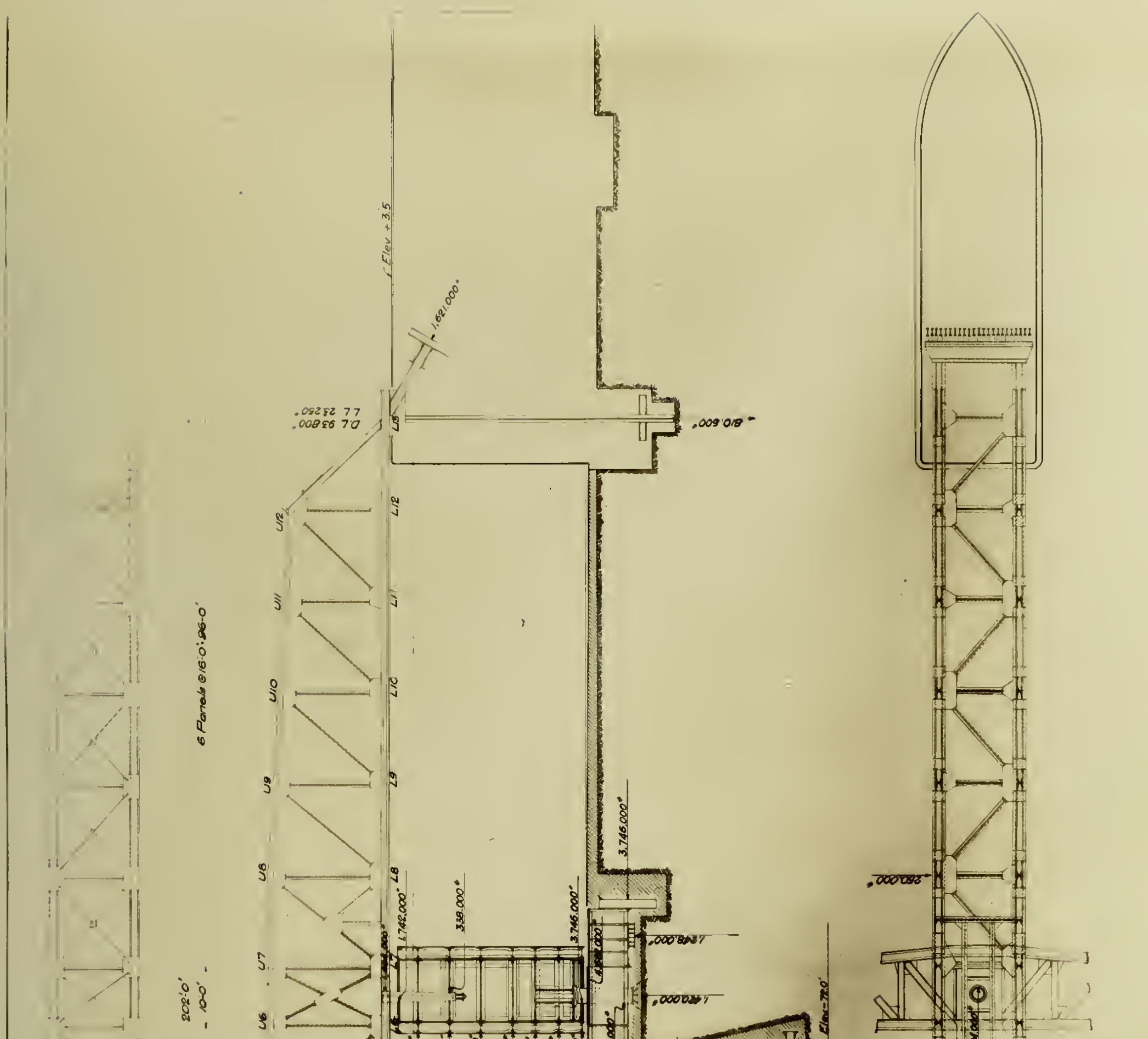
V.

DESIGN AND SPECIFICATIONS.

A diagram showing the general arrangement of the piers, lower and upper pivot supports, brace span and a section through the center box girder of movable leaf is given in Fig. 38. The principal reactions are noted and indicated by arrows in this figure.

At down stream pier, the stress from twin columns, which are the bottom chords of brace span, is delivered to a skewback and thence to cross box girder from which it is distributed by means of an I beam grillage, 8 feet by 20 feet in area. The plane of this grillage is inclined to the vertical 30°. Taking a line normal to this as the line of reaction, the pier was proportioned so that the line of stress passed well within outline of pier. The concrete surrounding grillage consisted of a 1:2 1/2:4 1/2 mixture, material elsewhere being 1:3:6. The unit pressure under grillage was designed at 75 pounds per square inch, and that over a symmetrical area of base did not exceed 100 pounds per square inch. The total uplift due to inclination of skewback ampunted to 810,500 pounds. This was resisted by the dead weight of the material above it, and it was found necessary to excavate below floor of channel 15 feet to secure sufficient anchorage.

The lower pivot receives its load in two ways, the dead weight of movable leaf and the horizontal thrust from movable leaf. The weight of the dam is 1,420,000 pounds and the thrust



6 Panels @ 16'-0" = 96'-0"
7 Panels @ 16'-0" = 96'-0"
202'-0"
Chicago Datum Elev 0.0
Elev -90.0
Elev +3.5

Fig. 38.

from dam 3,746,000 pounds, full cantilever load. The dead weight of movable leaf is carried from the cross girders in the center box girder to a casting which was machined and polished, and into which a bronze disc was fitted. See Fig. 39. The upper end of pivot was finished and polished and upon this the plane surface of bronze disc rests. This provides two smooth surfaces in contact upon which rotation may take place. The area in contact on the spherical surface of bronze disc is 691 square inches and is subjected to a unit pressure of 2,060 pounds per square inch. The area of the plane surface of bronze disc and the upper surface of pivot is 638 square inches and is subjected to a pressure of 2230 pounds per square inch. When in motion the horizontal thrust is nil, while the vertical pressure remains constant.

The lower pivot is supported for vertical load on a cast steel base resting on a shallow concrete footing thoroughly reinforced, and which is embedded in the solid rock. This casting is 4 feet 6 inches in diameter, making pressure per square inch of 625 pounds. The area of bottom of pivot in contact is 553 square inches with a unit pressure of 2,600 pounds per square inch.

The lower pivot is supported to carry the horizontal thrust of movable leaf by a box girder having two upper and two lower horizontal diaphragms. See Figs. 38 and 40. The bearing on the two upper diaphragms is 7 inches by 32 inches and the projected area of lower bearing surface of one diaphragm is 2 5/8 inches by 30 inches. The other diaphragm has no bearing on pivot, its use being to relieve web rivetting of girder from double service. The distance from the center of pressure of movable leaf to center of bearing on box girder is 1 foot 6 1/2 inches,

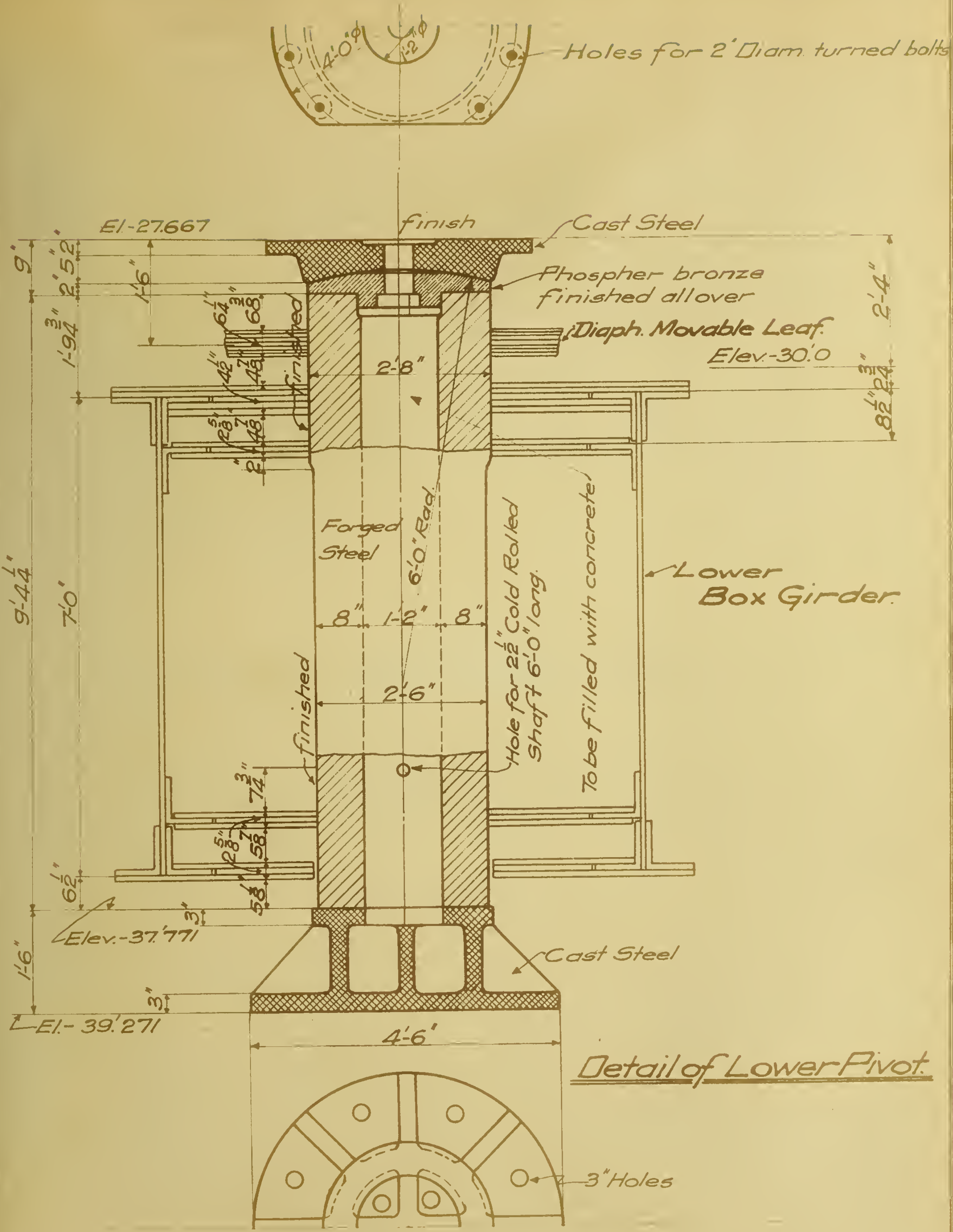
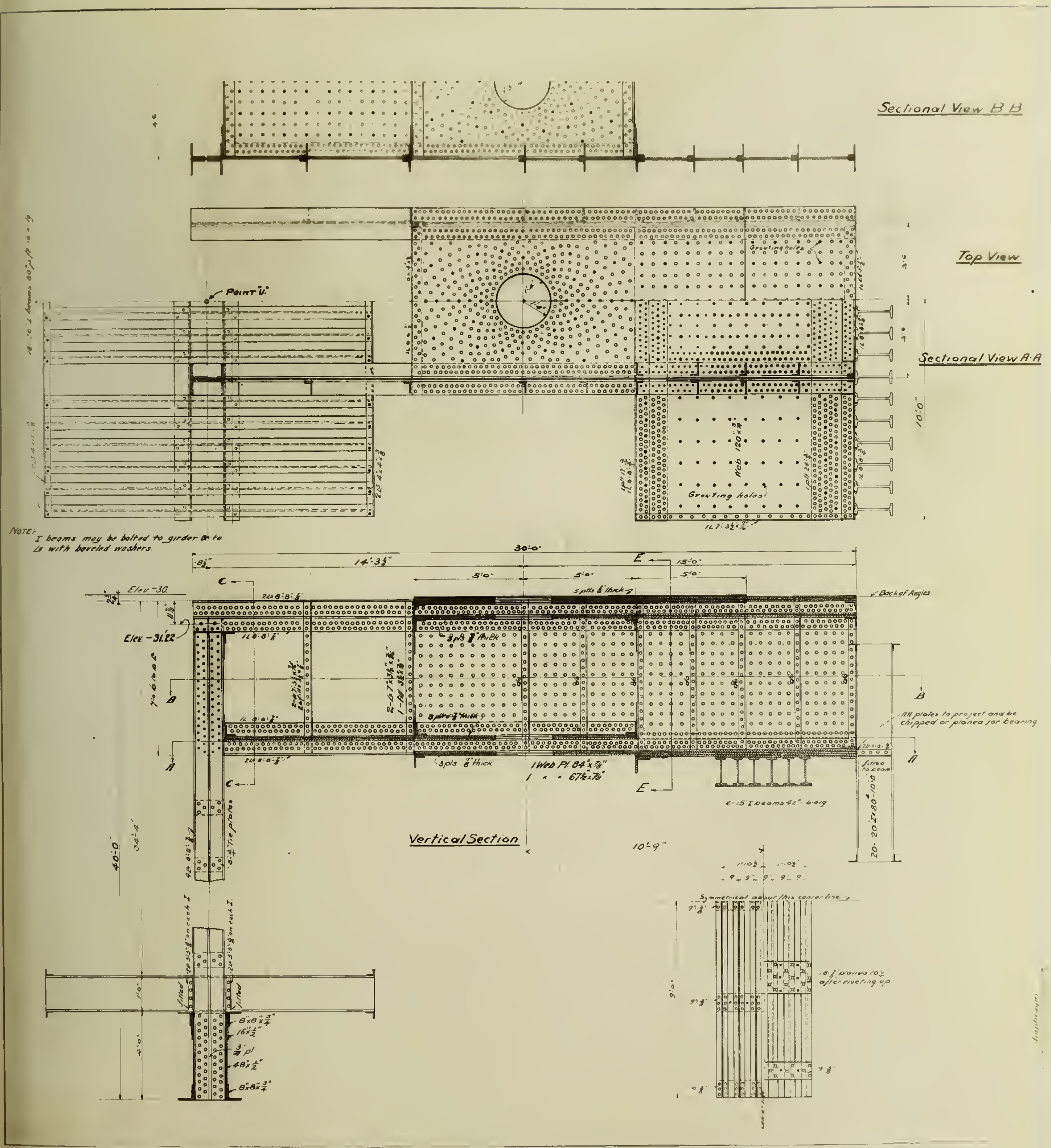

Holes for 2" Diam. turned bolts
4'-0"φ
1'-2"φ
El-27.667
finish
Cast Steel
Phospher bronze finished all over
Diaph. Movable Leaf.
Elev.-30.0
2'-4"
2'-8"
finished
Forged Steel
6'-0" Rad.
Hole for 22½" Cold Rolled Shaft 6'-0" long.
To be filled with concrete
Lower Box Girder.
8"
1'-2"
8"
2'-6"
9'-4¼"
7'-0"
1'-9¾"
1'-6"
Elev.-37.771
Cast Steel
El.-39.271
4'-6"
Detail of Lower Pivot.
3" Holes

Fig. 39.



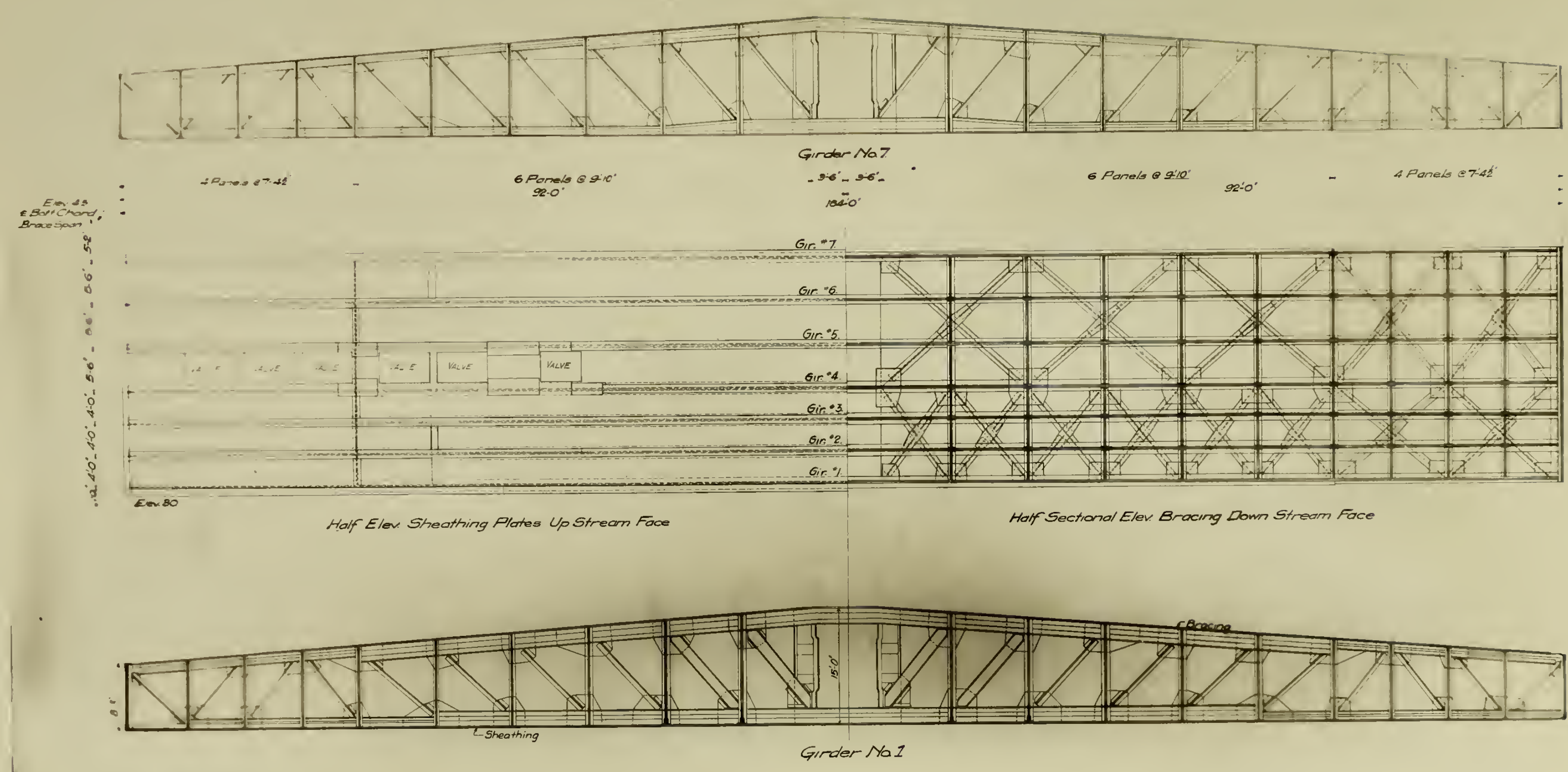
Sectional View B B
Top View
Sectional View A-A
Point U
Grouting holes
NOTE: I beams may be bolted to girder & to Ls with beveled washers.
30'-0"
14'-3½"
15'-0"
5'0"
Elev -30
Elev -31.22
Back of Angles
All plates to project and be chipped or planed for bearing
Vertical Section
10'-9"
Symmetrical about this center line

Fig. 40.

resulting in a bending moment of 69,301,000 inch pounds and a flexural stress of 22,400 pounds per square inch. This, combined with the vertical load, amounts to 24,630 pounds per square inch. For diagram loading see Fig. 38.

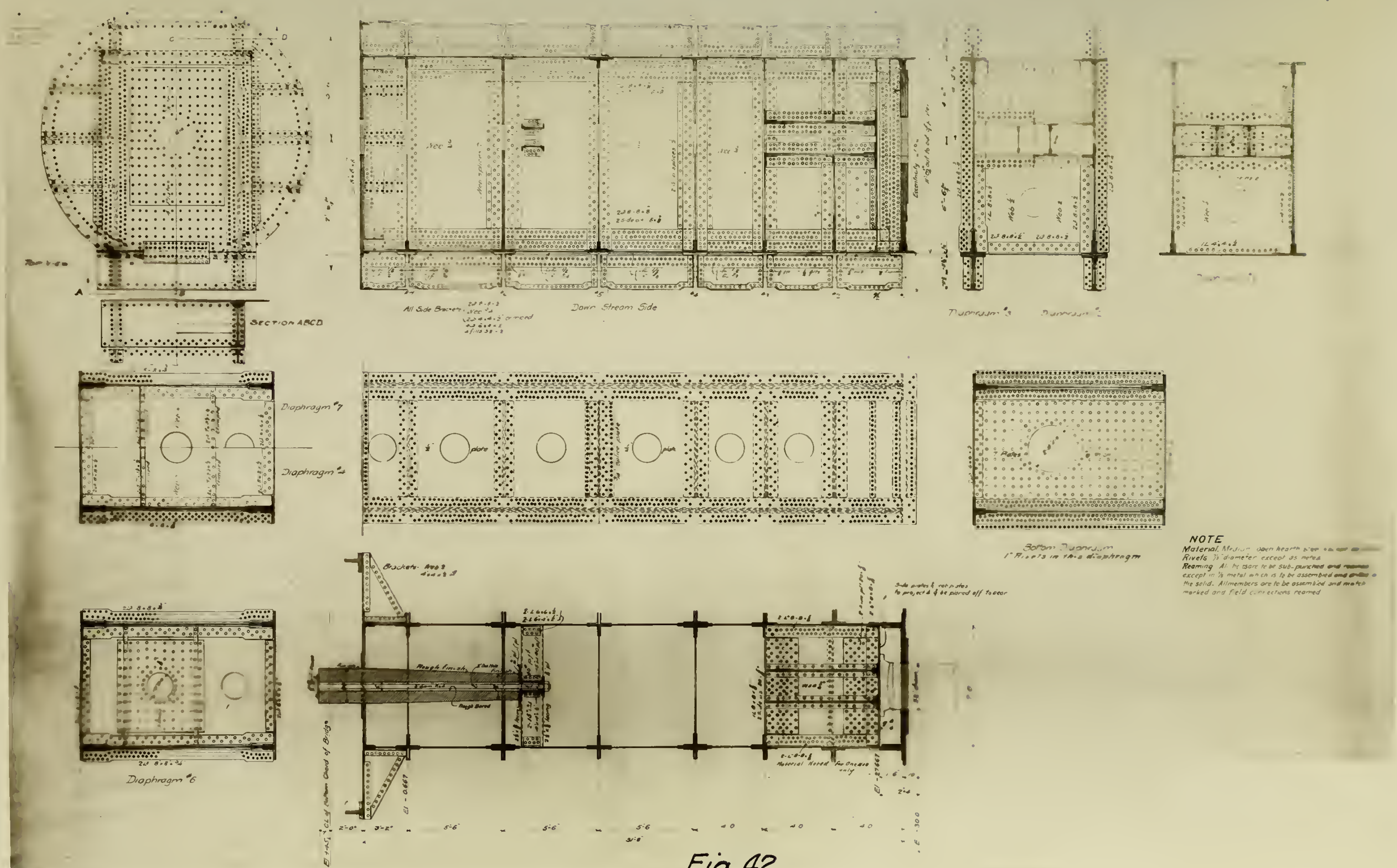
The lower pivot is supported in a box girder, and it subjects the box girder to bending and shearing stresses due to cantilevering of pivot. The end reaction is carried by a horizontal girder to a vertical grillage of 200 square feet in area with a unit pressure of 130 pounds per square inch and to a horizontal grillage 72 square feet in area, which is assisted by the area of horizontal girder and lower side of lower box girder. This downward pressure amounts to 1,248,000 pounds, which is equal also to the uplift on vertical anchorage.

The upper pivot carries the horizontal thrust from movable leaf to brace span. It is rigidly supported in movable leaf and is anchored to it by means of a rod 3 inches in diameter. The support in movable leaf consists of horizontal diaphragms located as shown in Fig. 42. The loads at these points are 1,742,000 pounds and 338,000 pounds with bearing areas 3 1/2 inches by 24 inches and 2 1/4 inches by 18 inches, making the pressure per square inch 20,800 pounds, and 8,300 pounds respectively. The distance from center of bearing in brace span diaphragm to center of bearing of center box girder diaphragm is 2 feet 0 7/8 inches, causing a bending moment of 34,925,000 inch pounds and a flexural stress of 25,900 pounds per square inch. These reactions are from full cantilever loading. The tension anchorage rod can receive no more load than the sliding friction of pivot in upper bearing. This amounts to 1/10 of 1,404,000 pounds or 140,800 ppunds, producing a unit stress of 20,000 pounds per square inch.



Girder No. 7
4 Panels @ 7'-4½"
6 Panels @ 9'-10"
92'-0"
3'-6" 3'-6"
184'-0"
6 Panels @ 9'-10"
92'-0"
4 Panels @ 7'-4½"
Elev. 43
℄ Bott. Chord
Brace Span
Gir. #7
Gir. #6
Gir. #5
Gir. #4
Gir. #3
Gir. #2
Gir. #1
VALVE
VALVE
Elev. 80
Half Elev. Sheathing Plates Up Stream Face
Half Sectional Elev. Bracing Down Stream Face
℄ Bracing
15'-0"
Sheathing
Girder No. 1

Fig. 41.



SECTION ABCD
All Side Brackets
Down Stream Side
Diaphragm #7
Diaphragm #4
Diaphragm #6
Bottom Diaphragm
1" Rivets in this diaphragm
Brackets
Rough Bored
Material Noted for Oneside only
NOTE
Material. Medium open hearth steel
Rivets 7/8" diameter except as noted
Reaming All holes to be sub-punched and reamed
except in 7/8 metal which is to be assembled and drilled
the solid. All members are to be assembled and match
marked and field connections reamed

Fig. 42.

The upper bearing of pivot in diaphragm in plane of bottom chord is provided with a cast steel ring forced into place and securely bolted. In this steel is a bronze ring 1 1/2 inches thick and 6 3/4 in. long. See Fig.47. At 1,404,000 pounds, total static pressure, the unit pressure on ring is 8,670 pounds per square inch. When dam is in motion this pressure is practically nil.

The leaf is composed of seven horizontal girders with vertical diaphragms at panel points, solid sheathing over up stream face and diagonal bracing in two systems over down stream face. See Figs. 41 and 42. At each end of the leaf is a girder into which the horizontal girders frame. At west end this girder carries the bearing directly into abutment through a heavy bearing plate, and at east abutment the end girder supports the bases for the lock struts. See Fig. 43.

On account of the increased unit pressures on the lower girders, it was found advisable to space them closer together than those at top, spacing being 4 feet and 5 1/2 feet respectively. All girders are connected together at center by center box girder which is composed of four vertical girders with diaphragms at each horizontal girder and also at the top and bottom to support center pivots. A cross girder near bottom transmits dead load to lower pivot.

The tables on following pages give the total stresses in each member of each horizontal girder for the three kinds of loading described previously. The maximum unit stresses, also, are given and the deflections for each girder acting as a cantilever. Diagram of the girder showing dimensions and sections precedes the corresponding stress table.

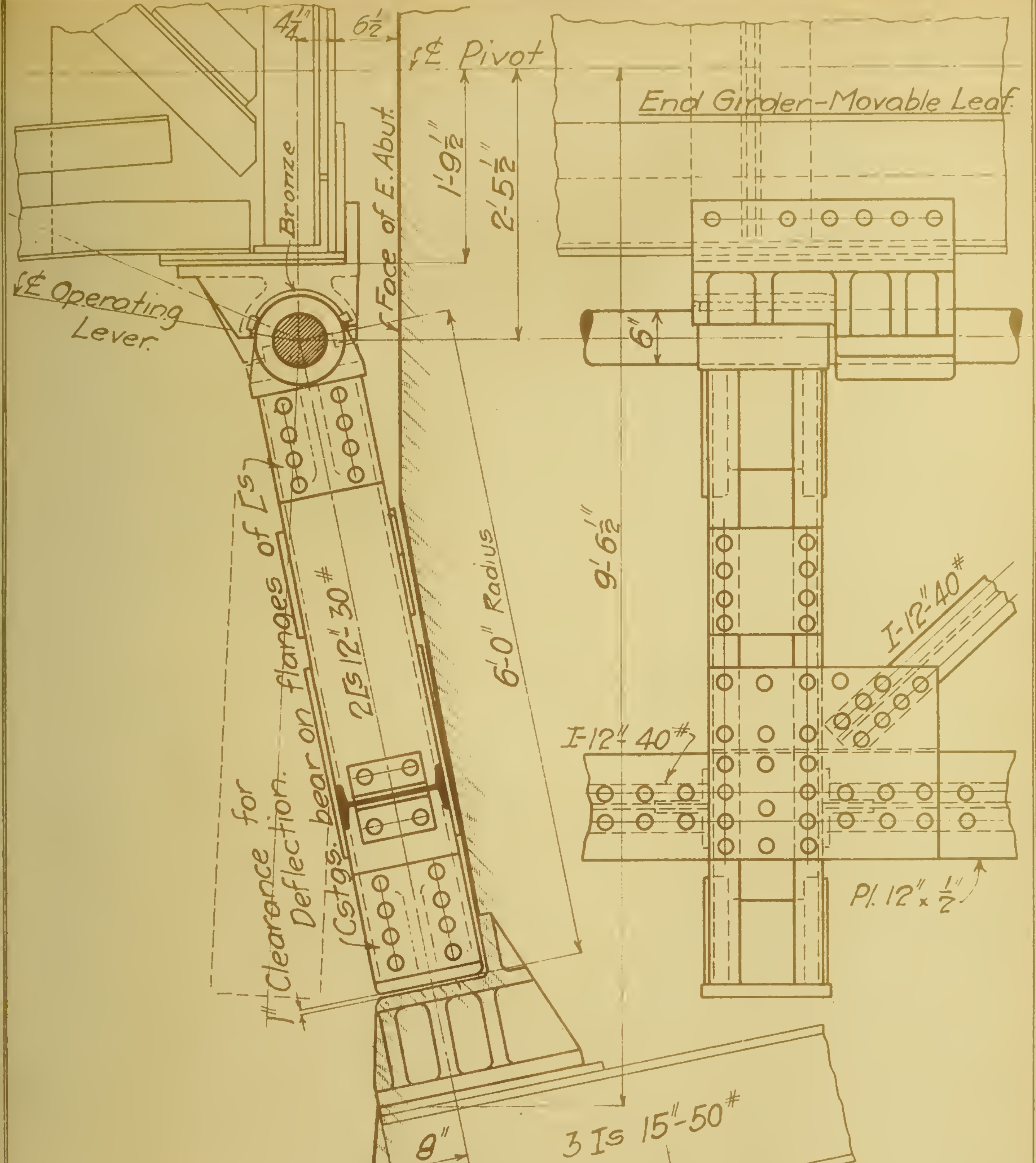
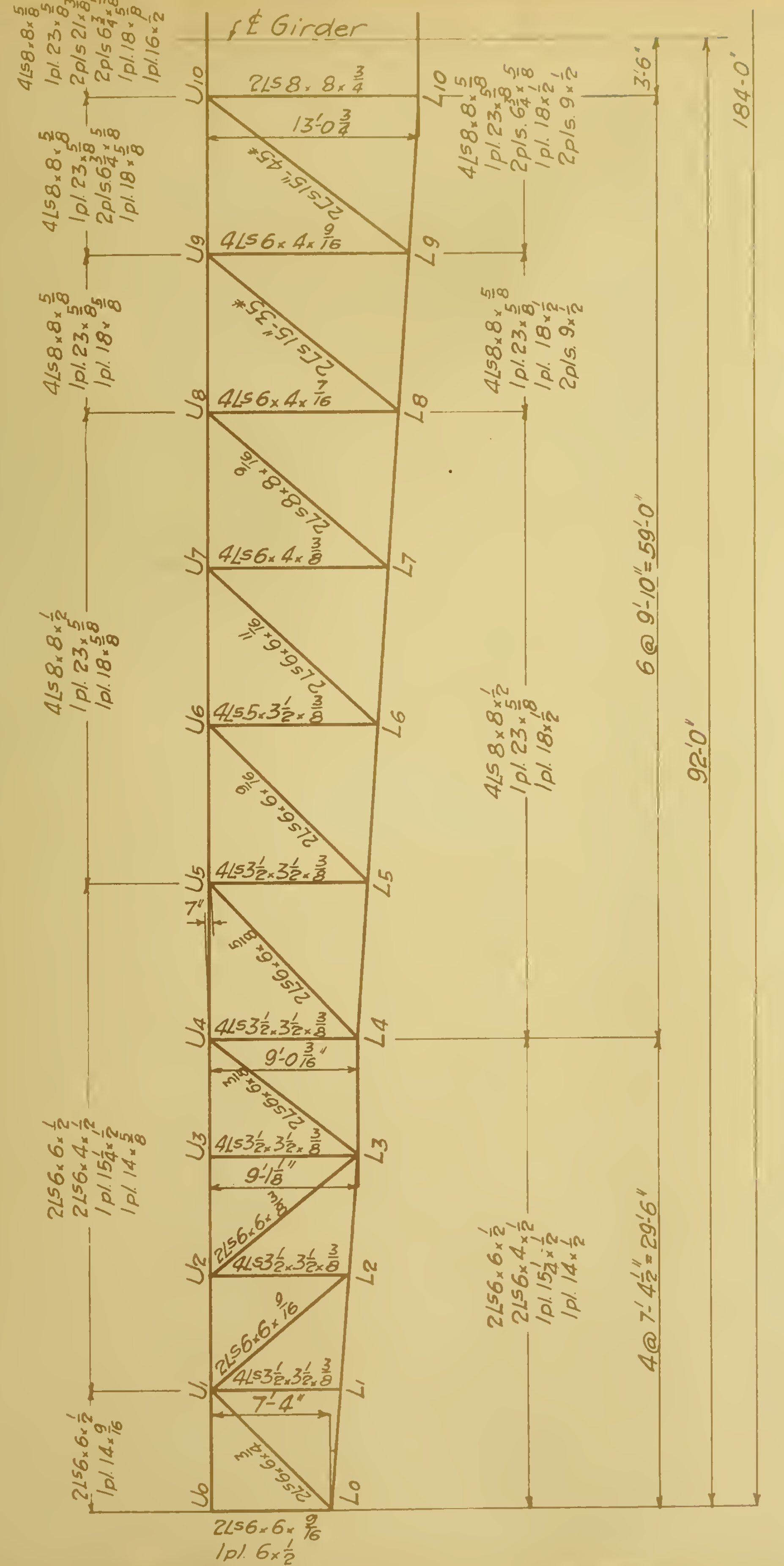

$4\frac{1}{4}''$
$6\frac{1}{2}$
℄ Pivot
End Girder-Movable Leaf.
$1'\text{-}9\frac{1}{2}''$
$2'\text{-}5\frac{1}{2}''$
Bronze
Face of E. Abut.
℄ Operating Lever.
6"
Clearance for flanges of [s
$2[s\ 12''\text{-}30^{\#}$
6'-0" Radius
$9'\text{-}6\frac{1}{2}''$
$I\text{-}12''\text{-}40^{\#}$
$I\text{-}12''\ 40^{\#}$
1" Clearance for Deflection.
(Cstgs. bear on
$Pl.\ 12''\times\frac{1}{2}''$
8"
$3\ Is\ 15''\text{-}50^{\#}$
$3\ Is\ 15''\text{-}50^{\#}$
2'6"
Face of E. Abut.
Detail of End Lock.

Fig. 43.



Girders #1, #3 and #4.

Girder #1 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 28.58
Load per lin. ft. = (28.6)62.5(2.75)=4914# = say 4910#

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1		0.			19.5	0.
U1U2		- 62.80			37.4	257.7
U2U3		- 132.16			37.4	760.8
U3U4		- 132.16			37.4	760.8
U4U5		- 237.38			37.4	2461.2
U5U6		- 412.15			56.6	3668.0
U6U7		- 593.43			56.6	6083.1
U7U8	Values same as for Girder #2	- 792.63	Values same as for Girder #2	Values same as for Girder #2	56.6	9043.2
U8U9		-1005.4			64.0	11030.3
U9U10		-1230.0			72.5	12752.0
U10U10		-1472.3			96.3	8702.4
LoL1		+ 16.92			35.6	39.5
L1L2		+ 16.92			35.6	39.5
L2L3		+ 62.98			35.6	273.3
L3L4		+ 236.85			35.6	1925.7
L4L5		+ 413.20			54.4	3848.9
L5L6		+ 594.63			54.4	6376.1
L6L7		+ 794.18			54.4	9477.8
L7L8		+1007.9			54.4	13084.0
L8L9		+1233.1			70.8	13166.7
L9L10		+1467.8			79.3	14805.0
L10L10		+1472.3			79.3	10568.3
LoUo		+ 18.12			15.9	100.3
LoU1		- 23.76			3.0) 16.9)	195.6

Girder #1 - Cantilever Stresses - (continued).

Mem- ber	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L1	Values same as for Girder #2	0.	Values same as for Girder #2	Values same as for Girder #2	9.92	0.
U1L2		+ 70.10			3.0) 12.9)	729.8
L2U2		- 49.30			9.92	437.4
U2L3		+110.12			3.0) 8.7)	1467.6
L3U3		+ 36.21			9.92	0.
L3U4		-166.34			3.0) 8.7)	2660.7
U4L4		+185.55			9.92	2094.7
L4U5		-237.11			4.4) 14.2)	2729.6
L5U5		+188.59			9.92	1478.2
L5U6		-257.38			3.8) 12.9)	2398.0
U6L6		+224.29			12.2	1451.6
L6U7		-295.20			3.8) 15.6)	2224.1
U7L7		+258.71			14.4	1439.0
L7U8		-330.11			5.0) 17.4)	2047.0
U8L8		+292.15			16.7	1422.9
L8U9		-362.92			9.4) 20.6)	1611.3
U9L9		+324.79			21.2	1264.7
L9U10		-394.35			9.4) 26.5)	1412.2
U10L10		+356.77			22.9	1297.1

$$\Sigma \frac{S'TL}{A} = 157586.1$$

$$\text{Deflection} = \frac{157,586,100}{30,000,000} = 5.25''$$

Girder #1 - Continuous

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =RT+S'	1" deflection R"T	1" deflection S" =RT+S'	A' for Max.	Max. Unit Stress
UoU1	0.	+ 0.		+ 0.		-	0.
U1U2	7.12	+ 274.18	+211.38	+221.98	+159.18	37.4	+ 5.65
U2U3	14.01	+ 384.65	+252.49	+311.42	+179.26	37.4	+ 6.75
U3U4	14.01	+ 384.65	+252.49	+311.42	+179.26	37.4	+ 6.75
U4U5	33.98	+ 518.21	+280.83	+419.55	+182.17	37.4	+ 7.51
U5U6	37.99	+ 674.92	+262.77	+546.43	+134.28	*46.6	- 8.84
U6U7	50.40	+ 777.38	+183.95	+629.37	+ 35.94	*46.6	-12.74
U7U8	62.44	+ 865.20	+ 72.57	+700.48	- 92.15	*46.6	-17.01
U8U9	65.28	+ 940.74	- 64.66	+761.64	-243.76	*52.7	-19.08
U9U10	66.04	+1007.0	-223.0	+815.32	-414.68	*58.7	-20.95
U10U10	40.05	+1071.3	-401.0	+867.38	-604.92	*78.3	-18.80
LoL1	2.18	- 147.78	-130.86	-119.64	-102.72	*27.1	- 4.83
L1L2	2.18	- 147.78	-130.86	-119.64	-102.72	*27.1	- 4.83
L2L3	7.55	- 274.99	-212.01	-222.64	-159.66	*27.1	- 7.82
L3L4	26.59	- 517.06	-280.21	-418.62	-181.77	*27.1	-10.34
L4L5	39.87	- 676.64	-263.44	-547.83	-134.63	54.4	+ 7.60
L5L6	52.83	- 778.93	-184.30	-630.64	- 36.01	54.4	+10.93
L6L7	65.44	- 866.90	- 72.72	-701.86	+ 92.32	54.4	+14.60
L7L8	77.43	- 943.02	+ 64.88	-763.48	+244.42	54.4	+18.53
L8L9	68.18	-1009.5	+223.6	-817.32	+415.78	70.8	+17.42
L9L10	68.14	-1068.1	+399.7	-864.72	+603.08	79.3	+18.51
L10L10	48.64	-1071.3	+401.0	-867.38	+604.92	79.3	+18.57
LoUo	5.53	0.	+ 18.12	0.	+ 18.12	15.9	+ 1.14
LoU1	10.81	+ 207.54	+183.78	+168.03	+144.27	16.9	+10.87

* Net areas, others are gross areas.

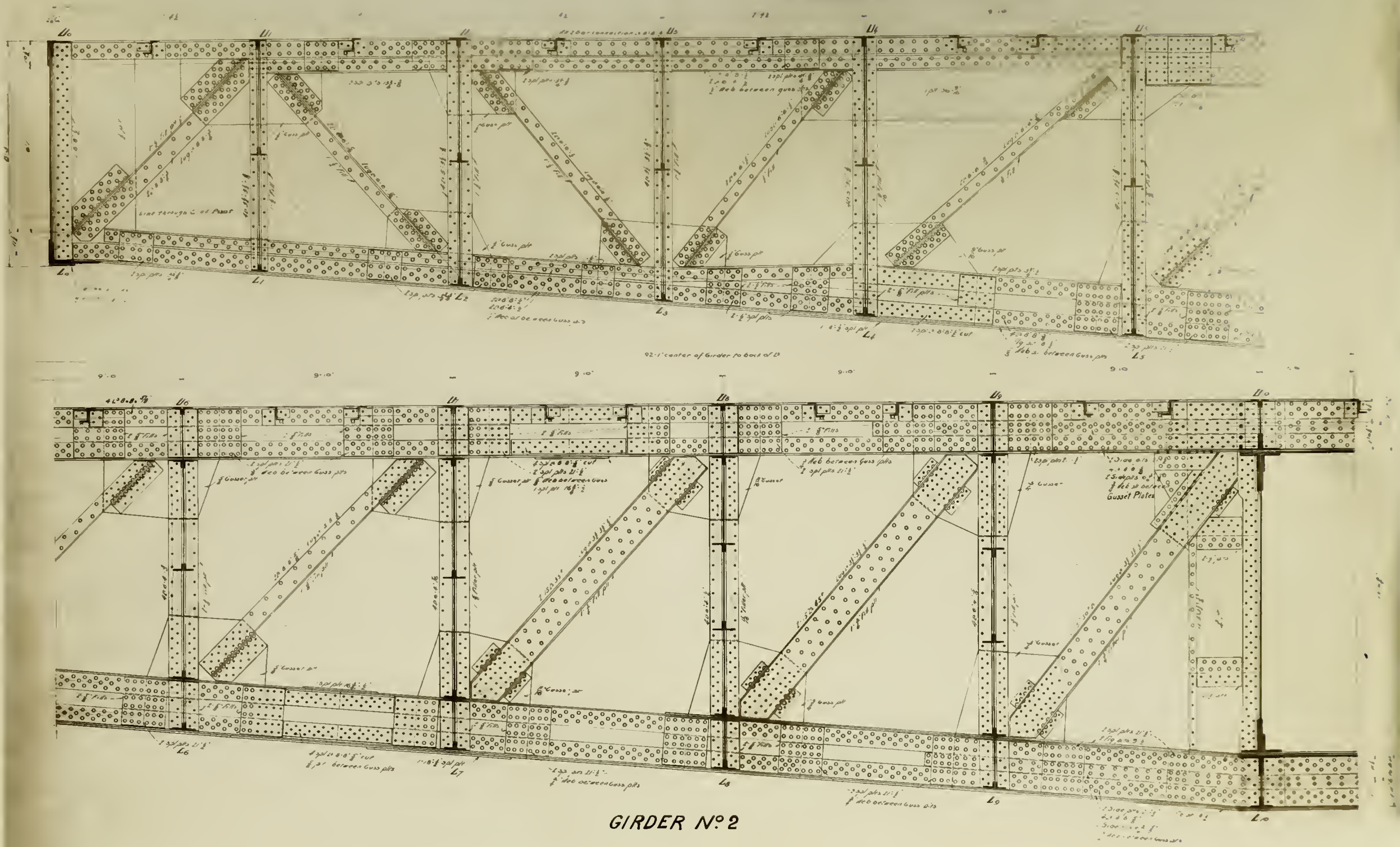
Girder #1 - Continuous - (continued)

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S'	A' for Max.	Max. Unit Stress
U1L1	0.	0.	0.	0.	0.	-	0.
U1L2	12.76	-193.74	-123.64	-156.85	- 86.75	*11.8	-10.48
L2U2	7.65	+136.28	+ 86.98	+110.34	+ 61.04	9.9	+ 8.78
U3L3	0.	0.	+ 36.21	0.	+ 36.21	9.9	+ 3.66
U2L3	14.80	-175.46	- 65.34	-142.06	- 31.94	8.7	+12.66
L3U4	21.31	+210.60	+ 44.26	+170.50	+ 4.16	* 8.0	-20.79
U4L4	11.68	-163.63	+ 21.92	-132.48	+ 53.07	9.9	+18.74
L4U5	15.86	+217.84	- 19.27	+176.37	- 60.74	*13.0	-18.24
L5U5	5.51	-111.15	+ 77.44	- 89.99	+ 98.60	9.9	+19.05
L5U6	8.97	+152.13	-105.25	+123.17	-134.21	*11.8	-21.81
U6L6	4.26	-104.03	+120.26	- 84.22	+140.07	12.2	+18.39
L6U7	6.54	+137.30	+157.90	+111.16	-184.04	*14.2	-20.79
U7L7	3.44	- 97.86	+160.85	- 79.23	+179.48	14.4	+18.00
L7U8	4.92	+125.41	-204.70	+101.54	-228.57	*16.3	-20.25
U8L8	2.85	- 92.65	+199.50	- 75.01	+217.14	16.7	+17.50
L8U9	3.25	+115.58	-247.34	+ 93.57	-269.35	*18.0	-20.16
U9L9	2.17	- 88.06	+236.73	- 71.30	+253.49	21.2	+15.32
L9U10	2.43	+107.31	-287.04	+ 86.88	-307.47	*24.0	-16.43
U10L10	1.93	- 83.95	+272.82	- 67.97	+288.80	22.9	+15.58
$\Sigma \frac{T^2L}{A}=$	997.02						

No deflection $R' = \frac{157,586,100}{997.02} = 158,100$ $R" = 293,600$ (1 arm)

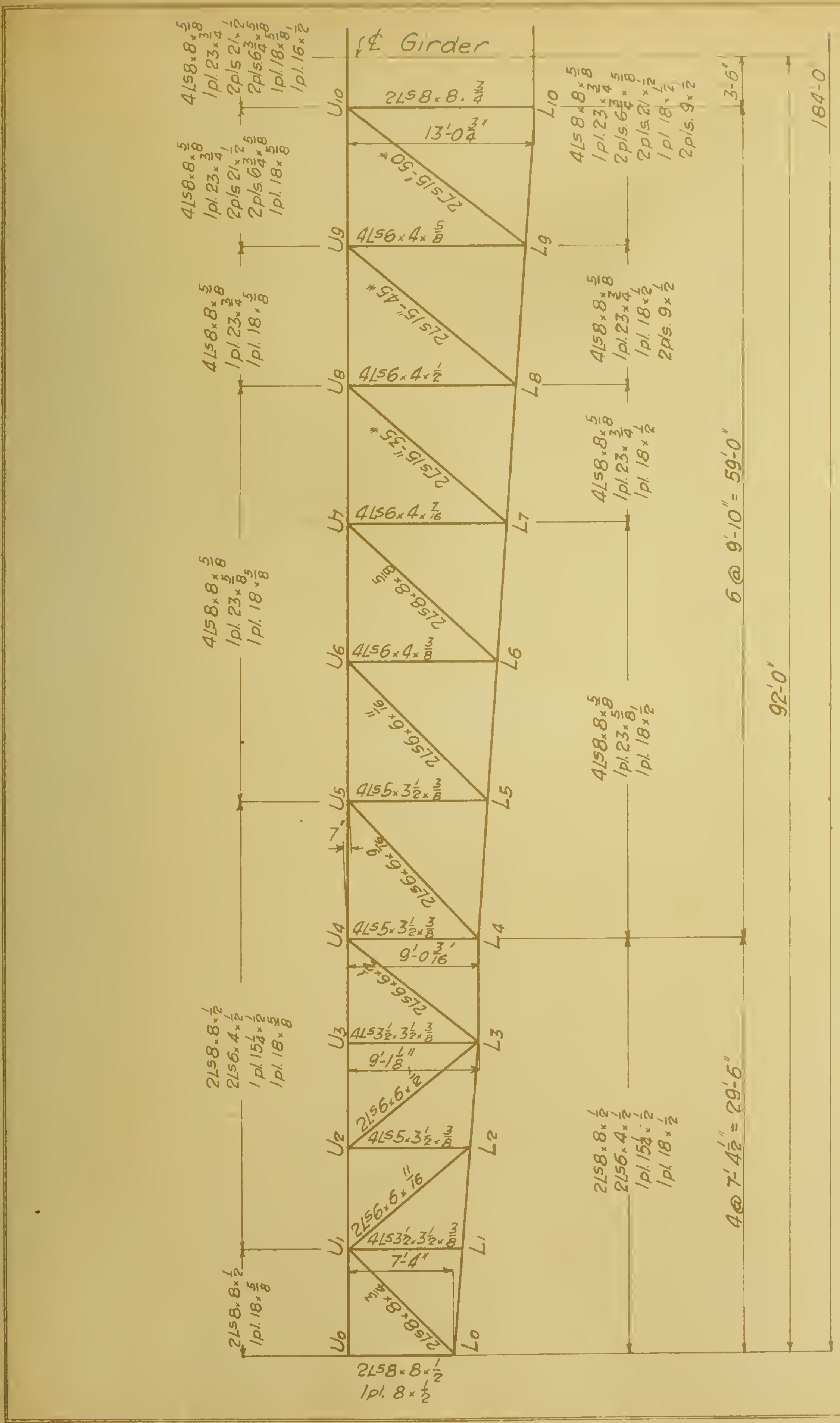
1" deflection $R" = \frac{4.25}{5.25}\ 158,100 = 128,000$ $R" = 323,700$ (1 arm)

* Net areas, others are gross.



GIRDER No. 2

NOTE
MATERIAL. Medium open hearth steel
RIVETS. 7/8" diameter
REAMING. All field connections and splices are to be reamed while assembled. All metal ¾" thick and over to be sub-punched and reamed assembled.



℄ Girder
U0 U1 U2 U3 U4 U5 U6 U7 U8 U9 U10
L0 L1 L2 L3 L4 L5 L6 L7 L8 L9 L10
2∠s 8×8×1/2
1 pl. 8×1/2
2∠s 8×8×1/2
1 pl. 18×5/8
2∠s 8×8×1/2
2∠s 6×4×1/2
1 pl. 15 1/4×1/2
1 pl. 18×5/8
4∠s 8×8×5/8
1 pl. 23×5/8
1 pl. 18×5/8
4∠s 8×8×5/8
1 pl. 23×3/4
1 pl. 18×5/8
4∠s 8×8×5/8
1 pl. 23×3/4
2 pls 21×1/2
2 pls 6 3/4×5/8
1 pl. 18×5/8
4∠s 8×8×5/8
1 pl. 23×3/4
2 pls 21×1/2
2 pls 6 3/4×5/8
1 pl. 18×5/8
1 pl. 16×1/2
2∠s 8×8×3/4
13'-0 3/4"
2 [s 15"-50#
4∠s 6×4×5/8
2 [s 15"-45#
4∠s 6×4×1/2
2 [s 15"-35#
4∠s 6×4×7/16
2∠s 8×8×5/8
4∠s 6×4×3/8
2∠s 6×6×11/16
4∠s 5×3 1/2×3/8
2∠s 6×6×9/16
7"
4∠s 5×3 1/2×3/8
9'-0 3/16"
2∠s 6×6×1/2
4∠s 3 1/2×3 1/2×3/8
9'-1 1/8"
2∠s 6×6×1/2
4∠s 5×3 1/2×3/8
2∠s 6×6×11/16
4∠s 3 1/2×3 1/2×3/8
7'-4"
2∠s 8×8×3/4
2∠s 8×8×1/2
2∠s 6×4×1/2
1 pl. 15 1/4×1/2
1 pl. 18×1/2
4∠s 8×8×5/8
1 pl. 23×5/8
1 pl. 18×1/2
4∠s 8×8×5/8
1 pl. 23×3/4
1 pl. 18×1/2
4∠s 8×8×5/8
1 pl. 23×3/4
1 pl. 18×1/2
2 pls. 9×1/2
4∠s 8×8×5/8
1 pl. 23×3/4
2 pls 6 3/4×5/8
2 pls 21×1/2
1 pl. 18×1/2
2 pls. 9×1/2
4 @ 7'-4 1/2" = 29'-6"
6 @ 9'-10" = 59'-0"
3'-6"
92'-0"
184'-0

Girder #2.

Girder #2 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 25.17 feet.
load per lin. ft. = (25.17) (62.5)4 = 6292# = say 6300#.

Member	S 1000#/in ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1	0.	0.	0.	88.5	26.8	0.
U1U2	- 12.79	- 80.58	-1.734	88.5	43.9	281.7
U2U3	- 26.92	- 169.56	-2.433	88.5	43.9	831.7
U3U4	- 26.92	- 169.56	-2.433	88.5	43.9	831.7
U4U5	- 48.35	- 304.59	-3.277	118.3	43.9	2690.4
U5U6	- 83.94	- 528.83	-4.269	118.0	64.0	4162.3
U6U7	-120.86	- 761.43	-4.917	118.0	64.0	6902.9
U7U8	-161.43	-1017.0	-5.473	118.0	64.0	10262.
U8U9	-204.78	-1290.1	-5.950	118.0	66.9	13539.
U9U10	-250.52	-1578.3	-6.370	118.0	96.3	12318.
U10U10	-299.85	-1889.1	-6.776	84.0	104.3	10310.
LoL1	+ 3.45	+ 21.71	+0.935	88.8	41.6	43.3
L1L2	+ 3.45	+ 21.71	+0.935	88.8	41.6	43.3
L2L3	+ 12.83	+ 80.81	+1.739	88.8	41.6	300.1
L3L4	+ 48.24	+ 303.91	+3.271	88.5	41.6	2114.5
L4L5	+ 84.15	+ 530.18	+4.280	118.4	61.8	4347.2
L5L6	+121.15	+ 762.96	+4.927	118.4	61.8	7201.6
L6L7	+161.75	+1019.0	+5.483	118.4	61.8	10705.
L7L8	+205.27	+1293.2	+5.965	118.4	64.7	14116.
L8L9	+251.13	+1582.1	+6.385	118.4	73.7	16229.
L9L10	+298.93	+1840.4	+6.755	118.4	103.1	14611.
L10L10	+299.85	+1889.1	+6.776	84.0	103.1	10430.
LoUo	+ 3.69	+ 23.24	+1.0	88.0	19.50	104.9
LoU1	- 4.84	- 30.49	-1.313	124.8	4.0) 22.9)	185.7
U1L1	0.	0.	0.	95.0	9.92	0.

Girder #2 - Cantilever Stresses - (continued).

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L2	+ 14.28	+ 89.94	+1.225	135.1	3.0) 15.6)	800.5
L2U2	- 10.04	- 63.25	-0.862	102.1	12.2	456.3
U2L3	+ 22.43	+ 141.29	+1.110	140.5	3.0) 11.5)	1519.4
L3U3	+ 7.38	+ 46.46	+0.	109.1	9.92	0.
L3U4	- 33.88	- 213.44	-1.332	140.5	3.0) 11.5)	2754.8
U4L4	+ 37.79	+ 238.08	+1.035	108.2	12.2	2185.4
L4U5	- 48.29	- 304.24	-1.378	155.4	3.3) 12.9)	4021.2
L5U5	+ 38.41	+ 241.98	+0.703	110.6	12.2	1542.2
L5U6	- 52.42	- 330.24	-0.962	161.7	3.7) 15.6)	2662.4
U6L6	+ 45.68	+ 287.79	+0.658	120.0	14.4	1578.0
L6U7	- 60.12	- 378.77	-0.868	168.3	5.0) 19.2)	2287.4
U7L7	+ 52.69	+ 331.95	+0.619	129.4	16.7	1592.1
L7U8	- 67.23	- 423.57	-0.793	175.1	11.3) 20.6)	1844.3
U8L8	+ 59.50	+ 374.85	+0.586	138.8	19.0	1604.3
L8U9	- 73.92	- 465.66	-0.731	182.2	11.3) 26.5)	1640.8
U9L9	+ 66.15	+ 416.75	+0.557	148.2	23.4	1470.1
L9U10	- 80.32	- 505.99	-0.679	189.4	11.3) 29.4)	1598.4
U10L10	+ 72.66	+457.76	+0.531	156.8	22.9	1664.3
				$\Sigma \frac{S'TL}{A} =$		173783.2

$$\text{Deflection} = \frac{173783000}{30000000} = 5.79''$$

Girder #2 - Continuous.

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =RT+S'	1" deflection R"T	1" deflection S" =RT+S'	A' for Max.	Max. Unit Stress.
UoU1	0.	0.	0.	0.	0.	-	0.
U1U2	6.063	+ 350.66	+270.08	+ 290.14	+209.56	43.9	+ 6.15
U2U3	11.933	+ 491.95	+322.39	+ 407.05	+237.49	43.9	+ 7.35
U3U4	11.933	+ 491.95	+322.39	+ 407.05	+237.49	43.9	+ 7.35
U4U5	28?952	+ 662.77	+358.18	+ 548.38	+243.79	43.9	+ 8.16
U5U6	33.600	+ 863.18	+334.35	+ 714.20	+185.37	*52.8	-10.03
U6U7	44.576	+ 994.22	+232.79	+ 822.62	+ 61.19	*52.8	-14.44
U7U8	55.218	+1106.5	+ 89.5	+ 915.56	-101?44	*52.8	-19.28
U8U9	62.450	+1203.1	- 87.0	+ 995.50	-294.60	*54.9	-23.50
U9U10	49.716	+1288.0	-290.3	+1065.7	-512.6	*75.8	-20.82
U10U10	36.983	+1370.2	-518.9	+1133.7	-755.4	*81.5	-23.18
LoL1	1.865	- 189.00	-167.29	- 156.38	-134.67	*31.6	- 5.30
L1L2	1.865	- 189.00	-167.29	- 156.28	-134.67	*31.6	- 5.30
L2L3	6.458	- 351.70	-270.89	- 291.00	-210.19	*31.6	- 8.57
L3L4	22.755	- 661.29	-357.38	- 547.15	-243.24	*35.0	-10.21
L4L5	35.093	- 865.38	-335.20	- 716.03	-185.85	61.8	+ 8.58
L5L6	46.505	- 996.20	-233.24	- 824.27	- 61.31	61.8	+12.35
L6L7	57.603	-1108.7	- 89.7	- 917.36	+101.64	61.8	+16.49
L7L8	65.106	-1206.0	+ 87.2	- 997.90	+295.30	64.7	+19.99
L8L9	65.500	-1291.1	+291.0	-1068.3	+513.8	73.7	+21.47
L9L10	52.413	-1366.0	+474.4	-1130.2	+710.2	103.1	+17.85
L10L10	37.413	-1370.2	+518.9	-1133.7	+755.4	103.1	+18.32
LoUo	4.513	0.	+ 23.24	0.	+ 23.24	19.5	+ 1.19
LoU1	7.995	+ 265.44	+234.95	+ 219.63	+189.14	22.9	+10.26

* Net areas, others are gross.

Girder #2 - Continuous - (continued).

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S'	A' for Max.	Max. Unit Stress.
U1L1	0.	0.	0.	0.	0.	-	0.
U1L2	10.907	-247.78	-157.84	-205.01	-115.07	*12.8	-12.33
L2U2	6.219	+174.30	+111.05	+144.21	+ 80.96	12.2	+ 9.92
U2L3	11.935	-224.41	- 83.12	-185.68	- 44.39	11.5	+12.29
L3U3	0.	0.	+ 46.46	0.	+ 46.46	9.9	+ 4.69
L3U4	17.193	+269.34	+ 55.90	+222.85	+ 9.41	* 9.5	-22.47
U4L4	9.501	-209.28	+ 28.80	-173.16	+ 64.92	12.2	+19.51
L4U5	18.212	+278.60	- 25.64	+230.52	- 73.72	*10.7	-28.43
L5U5	4.480	-142.15	+ 99.83	-117.61	+124.37	12.2	+19.83
L5U6	7.758	+194.57	-135.67	+160.99	-169.25	*12.8	-25.80
U6L6	3.608	-133.05	+154.74	-110.09	+177.70	14.4	+20.00
L6U7	5.245	+175.60	-203.17	+145.30	-233.47	*15.4	-24.60
U7L7	2.969	-125.16	+206.79	-103.56	+228.39	16.7	+19.88
L7U8	3.454	+160.40	-263.17	+132.72	-290.85	*18.0	-23.53
U8L8	2.509	-118.49	+256.36	- 98.04	+276.81	19.0	+19.73
L8U9	2.576	+147.81	-317.85	+122.30	-343.36	*22.8	-20.42
U9L9	1.965	-112.63	+304.12	- 93.19	+323.56	23.4	+17.81
L9U10	2.144	+137.25	-368.74	+113.56	-392.43	*25.1	-20.16
U10L10	1.931	-107.37	+350.39	- 80.84	+368.92	22.9	+20.00
$\Sigma \frac{T^2L}{A}=$	859.113						

For no deflection $R' = \frac{173,783,000}{859.113} = 202,200$ $\qquad$ $R'' = 377,400$ (1 arm)

For 1" deflection $R' = \frac{4.79}{5.79}\, 202,200 = 167,300$ $\qquad$ $R'' = 412,300$ (1 arm)

* Net areas, others are gross.

Girder #3 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 21.17
Load per lin. ft. = (21.17)62.5(4.0) = 5290#

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1	Values same as for Girder #2	0.	Values same as for Girder #2	Values same as for Girder #2	Values same as for Girder #1	0.
U1U2		- 67.66				277.7
U2U3		- 142.39				819.7
U3U4		- 142.39				819.7
U4U5		- 255.76				2651.7
U5U6		- 444.05				3951.9
U6U7		- 639.37				6554.0
U7U8		- 853.98				9743.2
U8U9		-1083.3				11884.2
U9U10		-1325.3				13739.0
U10U10		-1586.3				9376.0
LoL1		+ 18.23				42.5
L1L2		+ 18.23				42.5
L2L3		+ 67.86				294.4
L3L4		+ 255.19				2074.7
L4L5		+ 445.18				4146.9
L5L6		+ 640.65				6869.7
L6L7		+ 855.66				10211.4
L7L8		+1085.9				14093.9
L8L9		+1328.5				14186.0
L9L10		+1581.4				15951.1
L10L10		+1586.3				11386.3
LoUo		+ 19.52				108.0
LoU1		- 25.60				210.8

Girder #3 - Cantilever Stresses - (continued).

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L1	Values same as for Girder #2	0.	Values same as for Girder #2	Values same as for Girder #2	Values same as for Girder #1	0.
U1L2		+ 75.52				786.3
L2U2		- 53.11				471.2
U2L3		+118.64				1581.2
L3U3		+ 39.01				0.
L3U4		-179.22				2866.7
U4L4		+199.91				2256.8
L4U5		-255.47				2940.9
L5U5		+203.19				1592.6
L5U6		-277.30				2583.6
U6L6		+241.65				1564.0
L6U7		-318.05				2396.2
U7L7		+278.73				1550.5
L7U8		-355.67				2205.5
U8L8		+314.76				1533.0
L8U9		-391.01				1736.0
U9L9		+349.94				1362.6
L9U10		-424.87				1521.5
U10L10		+384.38				1397.5

$$\Sigma \frac{S'TL}{A} = 169741.4$$

$$\text{Deflection} = \frac{169,741,400}{30,000,000} = 5.66''$$

Girder #3 - Continuous.

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S'	A' for Max.	Max. Unit Stress
UoU1	Values same as for Girder #1	+ 0.	+ 0.	+ 0.		Values same as for Girder #1	0.
U1U2		+ 295.17	+227.51	+238.98	+171.32		+ 6.08
U2U3		+ 414.09	+271.70	+335.27	+192.88		+ 7.27
U3U4		+ 414.09	+271.70	+335.27	+192.88		+ 7.27
U4U5		+ 557.88	+302.12	+451.68	+195.92		+ 8.08
U5U6		+ 726.57	+282.52	+588.25	+144.20		- 9.53
U6U7		+ 836.88	+197.51	+677.57	+ 38.20		-13.72
U7U8		+ 931.43	+ 77.45	+754.12	- 99.86		-18.33
U8U9		+1012.7	- 70.6	+819.96	-263.34		-20.56
U9U10		+1084.1	-241.2	+877.74	-447.56		-22.58
U10U10		+1153.3	-433.0	+933.80	-652.50		-20.26
LoL1		- 159.09	-140.86	-128.80	-110.57		- 5.20
L1L2		- 159.09	-140.86	-128.80	-110.57		- 5.20
L2L3		- 296.04	-228.18	-239.68	-171.82		- 8.42
L3L4		- 556.64	-301.45	-450.67	-195.48		-11.12
L4L5		- 728.43	-283.25	-589.77	-144.59		+ 8.18
L5L6		- 838.56	-197.91	-678.92	- 38.27		+11.78
L6L7		- 933.26	- 77.60	-755.60	+100.06		+15.73
L7L8		-1015.2	+ 70.7	-821.94	+263.96		+19.96
L8L9		-1086.8	+242.1	-879.90	+448.60		+18.76
L9L10		-1149.8	+431.6	-930.94	+650.46		+19.94
L10L10		-1153.3	+433.0	-933.80	+652.50		+20.00
LoUo		0.	+ 19.52	0.	+ 19.52		+ 1.23

Girder #3 - Continuous - (continued).

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S'	A' for Max.	Max. Unit Stress
LoU1	Values same as for Girder #1	+223.43	+197.83	+180.90	+155.30	Values same as for Girder #1	+11.70
U1L1		0.	0.	0.	0.		0.
U1L2		-208.57	-133.05	-168.86	- 93.34		-11.28
L2U2		+146.71	+ 93.60	+118.78	+ 65.67		+ 9.45
U2L3		-188.90	- 70.26	-152.93	- 34.29		+13.64
L3U3		0.	+ 39.01	0.	+ 39.01		+ 3.94
L3U4		+226.72	+ 47.50	+ 183.56	+ 4.34		-22.40
U4L4		-176.16	+ 23.75	-142.62	+ 57.29		+20.19
L4U5		+234.52	- 20.95	+189.87	- 65.60		-19.65
L5U5		-119.65	+ 83.54	- 96.87	+106.32		+20.52
L5U6		+163.78	-113.52	+132.60	-144.70		-23.50
U6L6		-111.99	+129.66	- 90.67	+150.98		+19.81
L6U7		+147.81	-170.24	+119.68	-198.37		-22.40
U7L7		-105.35	+173.38	- 85.30	+193.43		+19.36
L7U8		+135.01	-220.66	+109.31	-246.36		-21.82
U8L8		- 99.74	+215.02	-80.75	+234.01		+18.85
L8U9		+124.42	-266.59	+100.73	-290.28		-21.61
U9L9		- 94.80	+255.14	- 76.76	+273.18		+16.51
L9U10		+115.52	-309.35	+ 93.53	-331.34		-17.70
U10L10		- 90.38	+294.00	- 73.17	+311.21		+16.79

For no deflection $R' = \frac{169,741,400}{997.02} = 170,200$ R"=316,500 (1 arm)

For 1" deflection $R'' = \frac{4.66}{5.66}\,170,200 = 137,800$ R"=348,900 (1 arm)

Girder #4 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 16.79
Load per lin. ft. = (16.8)62.5(4.75)=4990#

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1	Values same as for Girder #2	0.	Values same as for Girder #2	Values same as for Girder #2	Values same as for Girder #2	0.
U1U2		- 63.82				261.9
U2U3		- 134.31				773.2
U3U4		- 134.31				773.2
U4U5		- 241.25				2501.3
U5U6		- 418.86				3727.8
U6U7		- 603.10				6182.3
U7U8		- 805.54				9190.5
U8U9		-1021.8				11210.0
U9U10		-1250.1				12959.7
U10U10		-1496.3				8844.2
LoL1		+ 17.20				40.1
L1L2		+ 17.20				40.1
L2L3		+ 64.01				277.7
L3L4		+ 240.71				1957.0
L4L5		+ 419.93				3911.6
L5L6		+ 604.31				6480.0
L6L7		+ 807.12				9632.3
L7L8		+1024.3				13297.3
L8L9		+1253.1				13381.2
L9L10		+1491.7				15046.2
L10L10		+1496.3				10740.5
LoUo		+ 18.41				101.9
LoU1		+ 24.15				198.8

Girder #4 - Cantilever Stresses - (continued).

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L1	Values same as for Girder #2	0.	Values same as for Girder #2	Values same as for Girder #2	Values same as for Girder #1	0.
U1L2		+ 71.24				741.7
L2U2		- 50.10				444.5
U2L3		+111.91				1491.5
L3U3		+ 36.80				0.
L3U4		-169.05				2704.1
U4L4		+188.58				2128.8
L4U5		-240.97				2774.1
L5U5		+191.66				1502.3
L5U6		-261.57				2437.1
U6L6		+227.95				1475.3
L6U7		-300.01				2260.4
U7L7		+262.93				1462.5
L7U8		-335.49				2080.4
U8L8		+296.91				1446.1
L8U9		-368.83				1537.5
U9L9		+330.09				1285.3
L9U10		-400.77				1435.2
U10L10		+362.58				1318.3

$$\Sigma \frac{S'TL}{A} = 160153.9$$

$$\text{Deflection} = \frac{160,153,900}{30,000,000} = 5.34''$$

Girder #4 - Continuous.

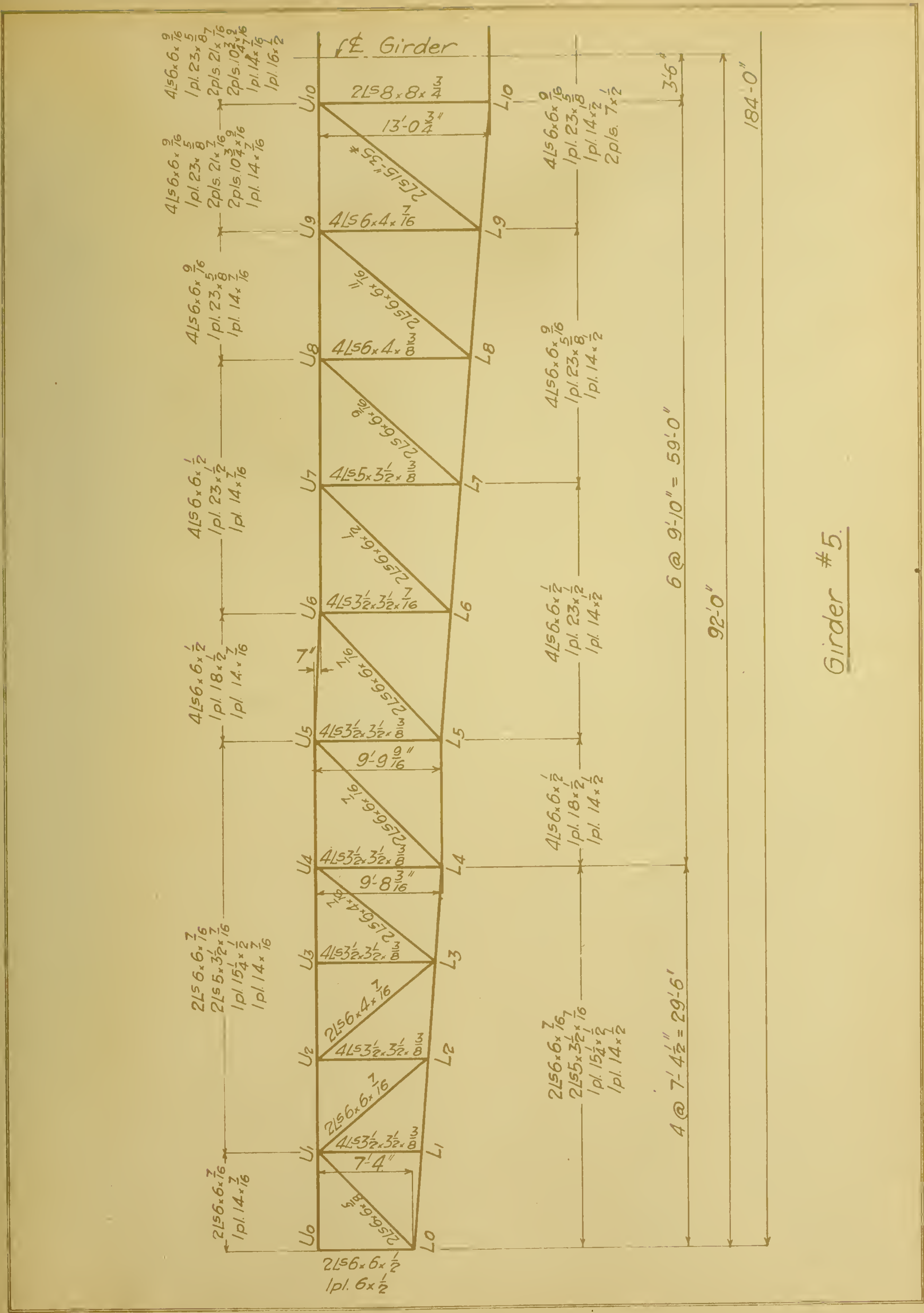
Member	$\frac{T^2L}{A}$	No deflection		1" deflection		A' for Max.	Max. Unit Stress
		R'T	S" =RT+S'	R"T	S" =RT+S'		
UoU1	Values same as for Girder #1	+ 0.		+ 0.		Values same as for Girder #1	0.
U1U2		+ 278.52	+214.70	+226.32	+162.50		+ 5.74
U2U3		+ 390.75	+256.44	+317.51	+183.20		+ 6.86
U3U4		+ 390.75	+256.44	+317.51	+183.20		+ 6.86
U4U5		+ 526.41	+285.16	+427.75	+186.50		+ 7.63
U5U6		+ 685.60	+266.74	+557.10	+138.24		- 8.99
U6U7		+ 789.68	+186.58	+641.67	+ 38.57		-12.94
U7U8		+ 878.90	+ 73.36	+714.17	- 91.37		-17.29
U8U9		+ 955.63	- 66.17	+776.52	-245.28		-19.39
U9U10		+1023.0	-227.1	+831.24	-418.86		-21.30
U10U10		+1088.3	-408.0	+884.32	-611.98		-19.11
LoL1		- 150.12	-132.92	-121.98	-104.78		- 4.90
L1L2		- 150.12	-132.92	-121.98	-104.78		- 4.90
L2L3		- 279.34	-215.33	-226.99	-162.98		- 7.94
L3L4		- 525.25	-284.54	-426.80	-186.09		-10.50
L4L5		- 687.35	-267.42	-558.52	-138.60		+ 7.72
L5L6		- 791.26	-186.95	-642.96	- 38.65		+11.11
L6L7		- 880.62	- 73.50	-715.57	+ 91.55		+14.84
L7L8		- 957.94	+ 66.36	-778.40	+245.90		+18.83
L8L9		-1025.5	+227.6	-833.28	+419.82		+17.70
L9L10		-1085.0	+406.7	-881.62	+610.08		+18.81
L10L10		-1088.3	+408.0	-884.32	+611.98		+18.87
LoUo		0.	+ 18.41	0.	+ 18.41		+ 1.16
LoU1		+ 210.83	+186.68	+171.31	+147.16		+11.05

Girder #4 - Continuous -(continued).

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =RT+S'	1" deflection R"T	1" deflection S" =RT+S'	A' for Max.	Max. Unit Stress
U1L1	Values same as for Girder #1	0.	0.	0.	0.	Values same as for Girder #1	0.
U1L2		-196.80	-125.56	-159.91	- 88.67		-10.64
L2U2		+138.44	+ 88.34	+112.49	+ 62.39		+ 8.92
U2L3		-178.24	- 66.33	-144.83	- 32.92		+12.86
L3U3		0.	+ 36.80	0.	+ 36.80		+ 3.72
L3U4		+213.93	+ 44.88	+173.83	+ 4.78		-21.13
U4L4		-166.22	+ 22.36	-135.03	+ 53.55		+19.05
L4U5		+221.29	- 19.68	+179.81	- 61.16		-18.54
L5U5		-112.90	+ 78.76	- 91.74	+ 99.92		+19.36
L5U6		+154.54	-107.03	+125.57	-136.00		-22.17
U6L6		-105.68	+122.27	- 85.87	+142.08		+18.68
L6U7		+139.48	-160.53	+113.33	-186.68		-21.13
U7L7		- 99.41	+163.52	- 80.78	+182.15		+18.26
L7U8		+127.40	-208.09	+103.52	-231.97		-20.58
U8L8		- 94.11	+202.80	- 76.47	+220.44		+17.78
L8U9		+117.40	-251.43	+ 95.40	-273.43		-20.49
U9L9		- 89.46	+240.63	- 72.69	+257.40		+15.57
L9U10		+109.01	-291.76	+ 88.58	-312.19		-16.70
U10L10		- 85.28	+277.30	- 69.30	+293.28		+15.83

For no deflection $R' = \frac{160,153,900}{997.02} = 160,600$ $R'' = 298,500$ (1 arm)

For 1" deflection $R' = \frac{4.34}{5.34}\ 160,600 = 130,500$ $R'' = 328,600$ (1 arm)



℄ Girder
Girder #5
184'-0"
92'-0"
6 @ 9'-10" = 59'-0"
4 @ 7'-4½" = 29'-6'
3'-6"
13'-0¾"
9'-9 9/16"
9'-8 3/16"
7'-4"
7"
U0
U1
U2
U3
U4
U5
U6
U7
U8
U9
U10
L0
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
2Ls 8x8x¾
2Ls 6x6x½
1pl. 6x½

Girder #5 - Cantilever Stresses .
Water level assumed at Elev. 0.0.
Average head = 11.67 feet.
Load per lin. ft. = (11 .67) (62.5) (5.5) = 4010.

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1		0.			16.2	0.
U1U2		- 51.29			30.9	254.7
U2U3		- 107.93			30.9	752.1
U3U4		- 107.93			30.9	752.1
U4U5	- 44.94	- 180.21	-3.047	118.0	30.9	2096.7
U5U6	- 79.16	- 317.43	-4.026	118.3	38.1	3968.0
U6U7	Values not given same as for Girder #2	- 484.66	Values not given same as for Girder #2	Values not given same as for Girder #2	40.6	6926.0
U7U8		- 647.33			40.6	10296.0
U8U9		- 821.12			46.2	12479.4
U9U10		-1004.57			76.7	9844.2
U10U10		-1202.40			84.7	8080.7
LoL1		+ 13.82			31.8	36.1
L1L2		+ 13.82			31.8	36.1
L2L3		+ 51.44			31.8	249.8
L3L4	+ 45.09	+ 180.81	+3.057	88.8	31.8	1543.4
L4L5	+ 79.00	+ 316.78	+4.018	118.4	39.0	3863.8
L5L6		+ 485.62			41.5	6826.0
L6L7		+ 648.60			41.5	10146.0
L7L8		+ 823.12			47.1	12341.7
L8L9		+1007.02			47.1	16164.1
L9L10		+1198.72			54.1	17723.2
L10L10		+1202.40			54.1	12651.2
LoUo		+ 14.80			14.5	89.8

Girder #5 - Cantilever Stresses - (continued)

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
LoU1		- 19.41			3.0) 14.2)	184.9
U1L1		0.			9.92	0.
U1L2		+ 57.25			3.0) 10.1)	723.5
L2U2		- 40.26			9.92	357.2
U2L3		+ 89.93			3.0) 8.36)	1234.4
L3U3		+ 29.57			9.92	0.
L3U4	- 28.62	- 114.75	-0.974		3.0) 8.36)	1382.7
U4L4	+ 30.84	+ 123.67	+0.757	116.2	9.92	1096.6
L4U5	- 47.75	- 191.48	-1.359	165.6	3.0) 10.1)	3288.6
L5U5	+ 48.02	+ 192.54	+1.191	117.6	9.92	2718.6
L5U6	- 59.27	- 237.68	-1.310		3.0) 10.1)	3844.2
U6L6		+ 183.18			11.5	1257.7
L6U7		- 241.09			3.0) 11.5)	2430.2
U7L7		+ 211.29			12.2	1387.2
L7U8		- 269.60			4.5) 12.9)	2152.2
U8L8		+ 238.60			14.4	1347.7
L8U9		- 296.40			3.8) 15.6)	2035.0
U9L9		+ 265.26			16.7	1311.2
L9U10		- 322.06			9.4) 20.6)	1380.1
U10L10		+ 291.37			22.9	1059.3

(S column) Values not given are same as for Girder #2

(T column) Values not given are same as for Girder #2

(L column) Values not given are same as for Girder #2

$$\Sigma \frac{S'TL}{A} = 166312.4$$

$$\text{Deflection} = \frac{166{,}312{,}400}{30{,}000{,}000} = 5.54''$$

Girder #5 - Continuous.

Member	$\frac{T^2L}{A}$	No deflection		1" deflection			
		R'T	S" =R'T+S'	R"T	S" =R"T+S'	A' for Max.	Max. Unit Stress
UoU1	0.					-	0.
U1U2	8.61	+227.70	+176.41	+186.60	+135.31	30.9	+ 5.71
U2U3	16.95	+319.45	+211.52	+261.79	+153.86	30.9	+ 6.85
U3U4	16.95	+319.45	+211.52	+261.79	+153.86	30.9	+ 6.85
U4U5	35.45	+400.05	+219.84	+327.84	+147.63	30.9	+ 7.11
U5U6	50.32	+528.59	+211.16	+433.18	+115.75	*30.0	- 9.92
U6U7	70.27	+645.60	+160.94	+529.06	+ 44.40	*34.8	-13.93
U7U8	87.04	+718.53	+ 71.20	+588.85	- 58.48	*34.8	-18.60
U8U9	90.43	+781.27	- 39.85	+640.25	-180.87	*39.4	-20.84
U9U10	62.42	+836.34	-168.23	+685.38	-319.19	*64.2	-15.65
U10U10	45.54	+889.74	-312.66	+729.13	-473.27	*70.0	-17.18
LoL1	2.44	-122.73	-108.91	-100.57	- 86.75	*24.1	- 4.52
L1L2	2.44	-122.73	-108.91	-100.57	- 86.75	*24.1	- 4.52
L2L3	8.45	-228.38	-176.94	-187.15	-135.71	*24.1	- 7.34
L3L4	26.10	-401.37	-220.56	-328.93	-148.12	*24.1	- 8.15
L4L5	49.00	-527.51	-210.73	-432.29	-115.51	39.0	+ 8.12
L5L6	69.25	-646.89	-161.27	-530.13	- 44.51	41.5	+11.70
L6L7	85.78	-719.95	- 71.35	-590.00	+ 58.60	41.5	+15.63
L7L8	89.44	-783.16	+ 39.96	-641.80	+181.32	47.1	+17.47
L8L9	102.49	-838.38	+168.64	-687.05	+319.97	47.1	+21.38
L9L10	99.88	-887.02	+311.70	-726.92	+471.80	54.1	+22.16
L10L10	71.30	-889.74	+312.66	-729.13	+473.27	54.1	+22.22
LoUo	6.07	0.	+ 14.80	0.	+ 14.80	14.5	+ 1.02
LoU1	12.50	+172.36	+152.95	+141.25	+121.84	14.2	+10.77

* Net areas, others are gross.

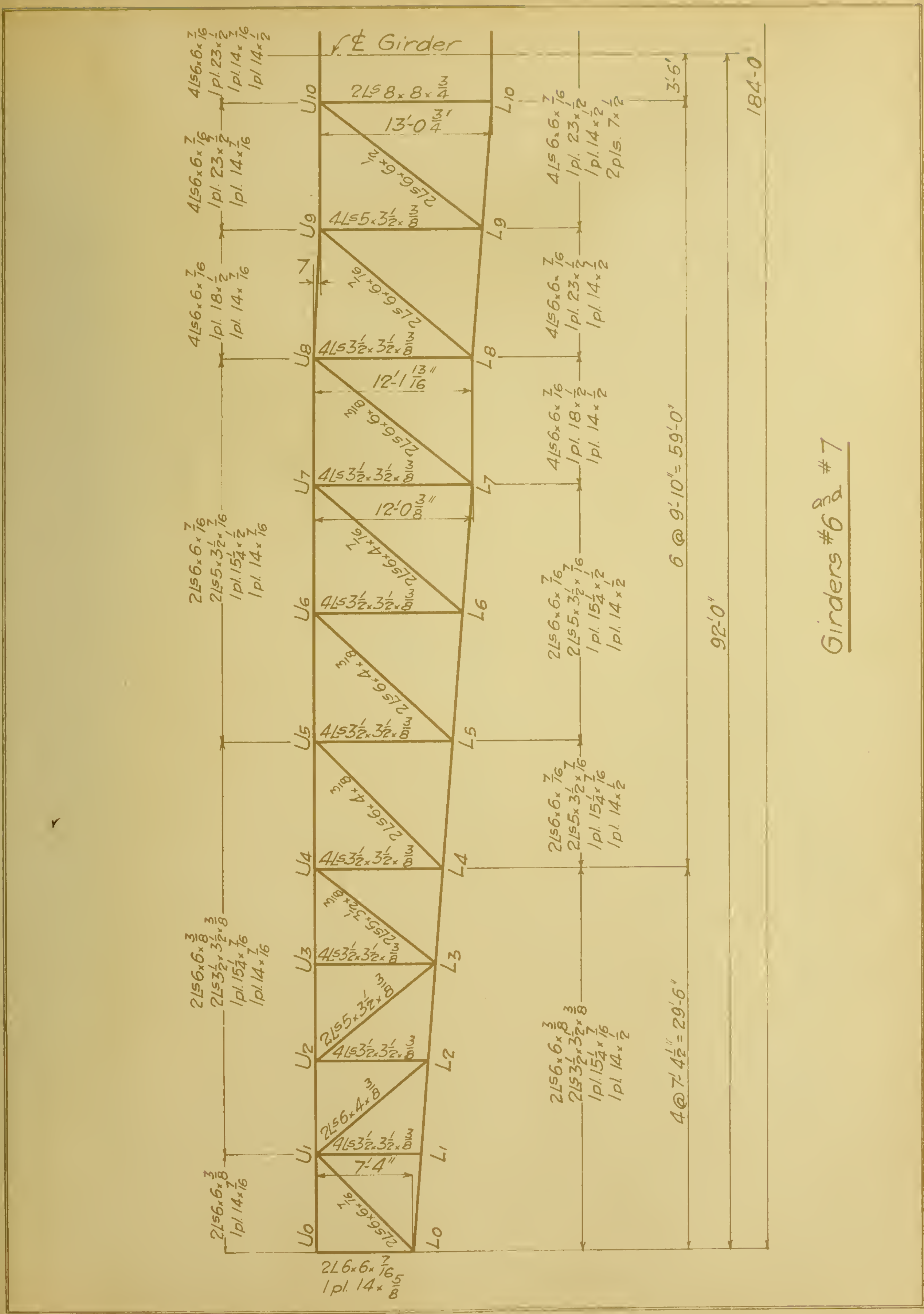
Girder #5 - Continuous - (continued)

Mem-ber	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S'	A' for Max.	Max. Unit Stress
U1L1	0.	0.	0.	0.	0.		0.
U1L2	15.49	-160.89	-103.64	-131.85	- 74.60	* 8.3	-12.49
L2U2	7.65	+113.18	+ 72.92	+ 92.75	+ 52.49	9.9	+ 7.36
U2L3	15.23	-145.72	- 55.79	-119.42	- 29.49	8.4	+10.71
L3U3	0.	0.	+ 29.57	0.	+ 29.57	9.9	+ 2.99
L3U4	11.74	+127.92	+ 13.17	+104.83	- 9.92	* 7.5	-15.30
U4L4	6.71	- 99.39	+ 24.28	- 81.45	+ 42.22	9.9	+12.49
L4U5	23.33	+178.38	- 13.10	+146.18	- 45.30	* 8.3	-23.07
L5U5	16.82	-156.38	+ 36.16	-128.15	+ 64.39	9.9	+19.45
L5U6	21.19	-172.04	- 65.64	+140.99	- 96.69	* 9.2	-25.84
U6L6	4.52	- 86.40	+ 96.78	- 70.80	+112.38	11.5	+15.93
L6U7	8.75	+114.03	-127.06	+ 93.45	-147.64	* 9.5	-25.38
U7L7	4.06	- 81.27	+130.02	- 66.60	+144.69	12.2	+17.32
L7U8	6.33	+104.15	-165.45	+ 85.36	-184.24	*11.8	-22.85
U8L8	3.31	- 76.94	+161.66	- 63.05	+175.55	14.4	+16.57
L8U9	5.02	+ 95.98	-200.42	+ 78.66	-217.74	*12.8	-23.16
U9L9	2.75	- 73.13	+192.13	- 59.93	+205.33	16.7	+15.88
L9U10	2.91	+ 89.12	-232.94	+ 73.03	-249.03	*17.2	-18.72
U10L10	1.93	- 69.72	+221.65	- 57.14	+234.23	22.9	+12.72
$\Sigma \frac{T^2L}{A}=$	1266.86						

For no deflection $R' = \frac{166,312,400}{1266.86} = 131,300$ $\quad$ R"=237,600 (1 arm)

For 1" deflection $R'' = \frac{4.54}{5.54}\ 131,300 = 107,600$ $\quad$ R"=261,300 (1 arm)

* Net areas, others are gross.


Girders #6 and #7
℄ Girder
184'-0
92'-0"
6 @ 9'-10" = 59'-0"
4 @ 7'-4½" = 29'-6"
3'-6'
13'-0¾'
12'-1 13/16"
12'-0⅜"
7'-4"
U0 U1 U2 U3 U4 U5 U6 U7 U8 U9 U10
L0 L1 L2 L3 L4 L5 L6 L7 L8 L9 L10
2L6×6×7/16
1pl. 14×5/8

Girder #6 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 6.17
Load per lin. ft. = (6.17) 62.5 (5.5) = 2120#

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
UoU1		0.				
U1U2		- 27.11				
U2U3		- 57.06				
U3U4		- 57.06				
U4U5		- 95.27				
U5U6		-156.69				
U6U7		-227.76				
U7U8		-306.68				
U8U9		-414.05				
U9U10		-531.10				
U10U10		-635.70				
LoL1		+ 7.31				
L1L2	Values same as for Girder #7	+ 7.31	Values same as for Girder #7	Values same as for Girder #7	Values same as for Girder #7	$\Sigma \frac{S'TL}{A} = \frac{2120}{370}$ (19,798,700) = 113,441,200 (See Girder #7)
L2L3		+ 27.19				
L3L4		+ 95.58				
L4L5		+157.18				
L5L6		+228.48				
L6L7		+307.64				
L7L8		+413.32				
L8L9		+532.40				
L9L10		+633.75				
L10L10		+635.70				
LoUo		+ 7.82				
LoU1		- 10.26				

Girder #6 - Cantilever Stresses - (continued).

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L1		0.				
U1L2		+ 30.26				
L2U2		- 21.28				
U2L3		+ 47.55				
L3U3		+ 15.63				
L3U4		- 60.69				
U4L4		+ 65.38				
L4U5	Values same as for Girder #7	- 86.23	Values same as for Girder #7	Values same as for girder #7	Values same as for Girder #7	
L5U5		+ 81.34				
L5U6		-103.85				
U6L6		+ 96.53				
L6U7		-119.88				
U7L7		+111.10				
L7U8		-168.48				
U8L8		+175.82				
L8U9		-188.86				
U9L9		+140.24				
L9U10		-170.27				
U10L10		+154.04				

$\Sigma \frac{S'TL}{A} = \frac{2120}{370}(19,798,700) = 113,441,200$ (See Girder #7)

$$\text{Deflection} = \frac{113,441,200}{30,000,000} = 3.78"$$

Girder #6 - Continuous.

Member	$\frac{T^2L}{A}$	No deflection R'T	S" =RT+S'	1" deflection R"T	S" =RT+S*	A' for Max.	Max. Unit Stress
UoU1		0.	0.	0.	0.		0.
U1U2		+126.80	+ 99.69	+ 93.25	+ 66.14		+ 3.76
U2U3		+177.88	+120.82	+130.82	+ 73.76	26.5	+ 4.56
U3U4		+177.88	+120.82	+130.82	+ 73.76	26.5	+ 4.56
U4U5		+222.76	+127.49	+163.83	+ 68.56	26.5	+ 4.81
U5U6		+274.81	+118.12	+202.11	+ 45.42		- 6.05
U6U7		+319.55	+ 91.89	+235.01	+ 7.25		- 8.79
U7U8		+358.53	+ 51.85	+263.68	- 43.00		-11.84
U8U9		+414.93	+ 0.88	+305.16	-108.89		-14.33
U9U10		+465.70	- 65.40	+342.50	-188.60	Values not given same as for Girder #7	-16.65
U10U10	Values same as for Girder #7	+495.44	-140.26	+364.37	-271.33		-17.18
LoL1		- 68.34	- 61.03	- 50.26	- 42.95		- 2.96
L1L2		- 68.34	- 61.03	- 50.26	- 42.95		- 2.96
L2L3		-127.17	- 99.98	- 92.75	- 65.56		- 4.85
L3L4		-223.47	-127.89	-164.35	- 68.77	*22.8	- 5.61
L4L5		-275.68	-118.50	-202.75	- 45.57		+ 5.09
L5L6		-320.56	- 92.08	-235.75	- 7.27		+ 7.19
L6L7		-359.67	- 52.03	-264.51	+ 43.13		+ 9.67
L7L8		-414.20	- 0.88	-304.62	+108.70		+11.42
L8L9		-466.85	+ 65.55	-343.34	+189.06		+13.76
L9L10		-493.92	+139.83	-363.25	+270.50		+13.87
L10L10		-495.44	+140.26	-364.37	+271.33		+13.91
LoUo		0.	+ 7.82	0.	+ 7.82		+ 0.41

* Net areas, others are gross.

Girder #6 - Continuous - (continued)

Member	$\frac{T^2 L}{A}$	No deflection R'T	No deflection S" =R'T+S'	1" deflection R"T	1" deflection S" =R"T+S"	A' for Max.	Max. Unit Stress
LoU1		+ 95.98	+ 85.72	+ 70.59	+ 60.33		+ 8.49
U1L1		0.	0.	0.	0.		0.
U1L2		- 89.59	- 59.33	- 65.89	- 35.63	* 6.4	- 9.27
L2U2		+ 63.02	+ 41.74	+ 46.35	+ 25.07	9.9	+ 4.22
U2L3		- 81.14	- 33.59	- 59.68	- 12.13		+ 7.80
L3U3		0.	+ 15.63	0.	+ 15.63		+ 1.58
L3U4	Values same as for Girder #7	+ 71.26	+ 10.57	+ 60.69	- 8.28		-11.45
U4L4		- 55.35	+ 10.03	- 40.70	+ 24.68	Values not given same as for Girder #7	+ 6.52
L4U5		+ 73.06	- 13.17	+ 54.98	- 31.25		- 13.47
L5U5		- 51.25	+ 30.09	- 37.69	+ 43.65		+ 8.22
L5U6		+ 65.41	- 38.44	+ 48.11	- 55.74		-16.23
U6L6		- 47.67	+ 48.86	- 35.06	+ 61.47		+ 9.75
L6U7		+ 59.24	- 60.64	+ 43.57	- 76.31		-16.00
U7L7		- 44.60	+ 66.50	- 32.80	+ 78.30		+11.22
L7U8		+ 87.90	- 80.58	+ 64.65	-103.83		-21.33
U8L8		- 92.63	+ 83.19	- 68.13	+107.69		+17.76
L8U9		+ 85.69	-103.17	+ 63.02	-125.84		-20.53
U9L9		- 40.72	+ 99.52	- 29.95	+110.29		+11.49
L9U10		+ 49.63	-120.64	+ 36.50	-133.77		-16.22
U10L10		- 38.82	+115.22	- 28.55	+125.49		+ 6.73

For no deflection $R' = \frac{113,441,200}{1,551.6} = 73,100$ $R'' = 122,000$ (1 arm)

For 1" deflection $R' = \frac{2.78}{3.78}\,73,100 = 53,800$ $R'' = 141,300$ (1 arm)

* Net areas, others are gross.

Girder #7 - Cantilever Stresses.
Water level assumed at Elev. 0.0.
Average head = 1.71 feet.
Load per lin. ft. = (1.71) (62.5) (3.42)=365.5#=say 370#.

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	S'TL / A
UoU1	0.	0.	0.	88.5	14.9	0.
U1U2	- 12.79	- 4.73	-1.734	88.5	26.5	27.4
U2U3	- 26.92	- 9.96	-2.433	88.5	26.5	80.9
U3U4	- 26.92	- 9.96	-2.433	88.5	26.5	80.9
U4U5	- 44.94	- 16.63	-3.047	118.0	26.5	225.6
U5U6	- 73.91	- 27.35	-3.759	118.0	30.9	392.5
U6U7	-107.44	- 39.75	-4.371	118.0	30.9	663.4
U7U8	-144.66	- 53.52	-4.904	118.0	30.9	1002.3
U8U9	-195.30	- 72.26	-5.675	118.3	35.4	1370.5
U9U10	-250.52	- 92.69	-6.370	118.0	37.9	1838.2
U10U10	-299.85	-110.95	-6.776	84.0	44.9	1406.5
LoL1	+ 3.45	+ 1.28	+0.935	88.8	27.4	3.9
L1L2	+ 3.45	+ 1.28	+0.935	88.8	27.4	3.9
L2L3	+ 12.83	+ 4.75	+1.739	88.8	27.4	26.8
L3L4	+ 45.08	+ 16.68	+3.056	88.8	27.4	165.2
L4L5	+ 74.14	+ 27.43	+3.771	118.4	30.9	396.4
L5L6	+107.77	+ 39.88	+4.385	118.4	31.8	651.0
L6L7	+145.11	+ 53.69	+4.919	118.4	31.8	983.4
L7L8	+194.96	+ 72.14	+5.665	118.0	36.2	1332.1
L8L9	+251.13	+ 92.92	+6.385	118.4	38.7	1815.2
L9L10	+298.93	+110.60	+6.755	118.4	45.7	1935.9
L10L10	+299.85	+110.95	+6.776	84.0	45.7	1381.9
LoLo	+ 3.69	+ 1.37	+1.0	88.0	18.9	6.4
LoD1	- 4.84	- 1.79	-1.313	124.8	2.6) 10.1)	23.1

Girder #7 - Cantilever Stresses - (continued).

Member	S 1000#/lin ft.	S' Actual load	T 1# at Uo	L Inches	A Gross	$\frac{S'TL}{A}$
U1L1	0.	0.	0.	95.0	9.92	0.
U1L2	+ 14.28	+ 5.28	+1.225	135.1	2.6) 7.2)	89.2
L2U2	- 10.04	- 3.72	-0.862	102.1	9.92	33.0
U2L3	+ 22.43	+ 8.30	+1.110	140.5	2.2) 6.1)	155.9
L3U3	+ 7.38	+ 2.73	0.	109.1	9.92	0.
L3U4	- 28.63	- 10.59	-0.975	140.5	2.2) 6.1)	174.8
U4L4	+ 30.84	+ 11.41	+0.757	116.2	9.92	101.2
L4U5	- 40.68	- 15.05	-0.999	165.6	3.0) 7.2)	244.2
L5U5	+ 38.37	+ 14.20	+0.701	125.6	9.92	126.0
L5U6	- 48.99	- 18.13	-0.895	172.3	3.0) 7.2)	273.9
U6L6	+ 45.53	+ 16.85	+0.652	135.0	9.92	149.5
L6U7	- 56.54	- 20.92	-0.810	179.3	3.0) 8.4)	266.6
U7L7	+ 52.41	+ 19.39	+0.610	144.4	9.92	172.2
L7U8	- 79.47	- 29.40	-1.202	186.4	3.0) 8.7)	563.2
U8L8	+ 82.94	+ 30.69	+1.267	145.8	9.92	571.4
L8U9	- 89.09	- 32.96	-1.172	182.2	3.0) 10.1)	537.3
U9L9	+ 66.15	+ 24.48	+0.557	148.2	12.2	165.6
L9U10	- 80.32	- 29.72	-0.679	189.4	3.0) 11.5)	263.5
U10L10	+ 72.66	+ 26.88	+0.531	156.8	22.9	97.8

$$\Sigma \frac{S'TL}{A} = 19798.7$$

$$\text{Deflection} = \frac{19,798,700}{30,000,000} = 0.66''$$

Girder #7 - Continuous.

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =RT+S'	1" deflection R"T	1" deflection S" =RT+S'	A' for Max.	Max. Unit Stress.
UoU1	0.	+ 0.	0.	- 0.	0.	-	0.
U1U2	10.0	+22.13	+17.40	-11.41	- 16.14	26.5	+0.65
U2U3	19.8	+31.04	+21.08	-16.01	- 25.97	*19.9	-1.31
U3U4	19.8	+31.04	+21.08	-16.01	- 25.97	*19.9	-1.31
U4U5	41.3	+38.88	+22.25	-20.05	- 36.68	*19.9	-1.84
U5U6	54.0	+47.96	+20.61	-24.73	- 52.08	*25.9	-2.01
U6U7	72.9	+55.77	+16.02	-28.76	- 68.51	*25.9	-2.65
U7U8	91.8	+62.57	+ 9.05	-32.27	- 85.79	*25.9	-3.31
U8U9	107.6	+72.41	+ 0.15	-37.34	-109.60	*28.9	-3.79
U9U10	126.3	+81.28	-11.41	-41.91	-134.60	*31.9	-4.22
U10U10	85.9	+86.47	-24.48	-44.59	-155.54	*37.0	-4.20
LoL1	2.8	-11.93	-10.65	+ 6.15	+ 7.43	*20.6	-0.51
L1L2	2.8	-11.93	-10.65	+ 6.15	+ 7.43	*20.6	-0.51
L2L3	9.8	-22.19	-17.44	+11.44	+ 16.19	*20.6	-0.85
L3L4	30.3	-39.00	-22.32	+20.11	+ 36.79	27.4	+1.34
L4L5	54.5	-48.11	-20.68	+24.81	+ 52.24	30.9	+1.69
L5L6	71.6	-55.95	-16.07	+28.85	+ 68.73	31.8	+2.16
L6L7	90.1	-62.77	- 9.08	+32.37	+ 86.06	31.8	+2.71
L7L8	104.6	-72.29	- 0.15	+37.28	+109.42	36.2	+3.02
L8L9	124.7	-81.48	+11.44	+42.02	+134.94	38.7	+3.49
L9L10	118.2	-86.20	+24.40	+44.45	+155.05	45.7	+3.39
L10L10	84.4	-86.47	+24.48	+44.59	+155.54	45.7	+3.40
LoUo	4.7	0.	+ 1.37	+ 6.58	+ 7.95	18.9	+0.42
LoU1	16.9	+16.75	+14.96	- 8.64	- 10.43	10.1	+1.48

* Net areas, others are gross.

Girder #7 - Continuous - (continued).

Member	$\frac{T^2L}{A}$	No deflection R'T	No deflection S" =RT+S'	1" deflection R"T	1" deflection S" =RT+S'	A' for Max.	Max. Unit Stress
U1L1	0.	0.	0.	0.	0.	-	0.
U1L2	20.7	-15.64	-10.36	+ 8.06	+ 13.34	7.2	+1.85
L2U2	7.6	+11.00	+ 7.28	- 5.67	- 9.39	* 8.4	-1.12
U2L3	20.9	-14.16	- 5.86	+ 7.30	+ 15.60	6.1	+2.55
L3U3	0.	0.	+ 2.73	0.	+ 2.73	9.9	+0.28
L3U4	16.1	+12.44	+ 1.85	- 6.41	- 17.00	* 5.3	-3.21
U4L4	6.7	- 9.66	+ 1.75	+ 4.98	+ 16.39	9.9	+1.66
L4U5	16.2	+12.75	- 2.30	- 6.58	- 21.63	* 6.4	-3.38
L5U5	6.2	- 8.95	+ 5.25	+ 4.61	+ 18.81	9.9	+1.90
L5U6	13.5	+11.42	- 6.71	- 5.89	- 24.02	* 6.4	-3.75
U6L6	5.8	- 8.32	+ 8.53	+ 4.29	+ 21.14	9.9	+2.14
L6U7	10.3	+10.34	-10.58	- 5.33	- 26.25	* 7.5	-3.50
U7L7	5.4	- 7.78	+11.61	+ 4.01	+ 23.40	9.9	+2.36
L7U8	23.0	+15.34	-14.16	- 7.91	- 37.31	* 7.9	-4.72
U8L8	23.6	-16.17	+14.52	+ 8.34	+ 39.03	9.9	+3.94
L8U9	19.1	+14.96	-18.00	- 7.71	- 40.67	* 9.2	-4.42
U9L9	3.8	- 7.11	+17.37	+ 3.67	+ 28.15	12.2	+2.31
L9U10	6.0	+ 8.66	-21.06	- 4.47	- 34.19	*10.5	-3.26
U10L10	1.9	- 6.78	+20.10	+ 3.49	+ 30.37	22.9	+1.33

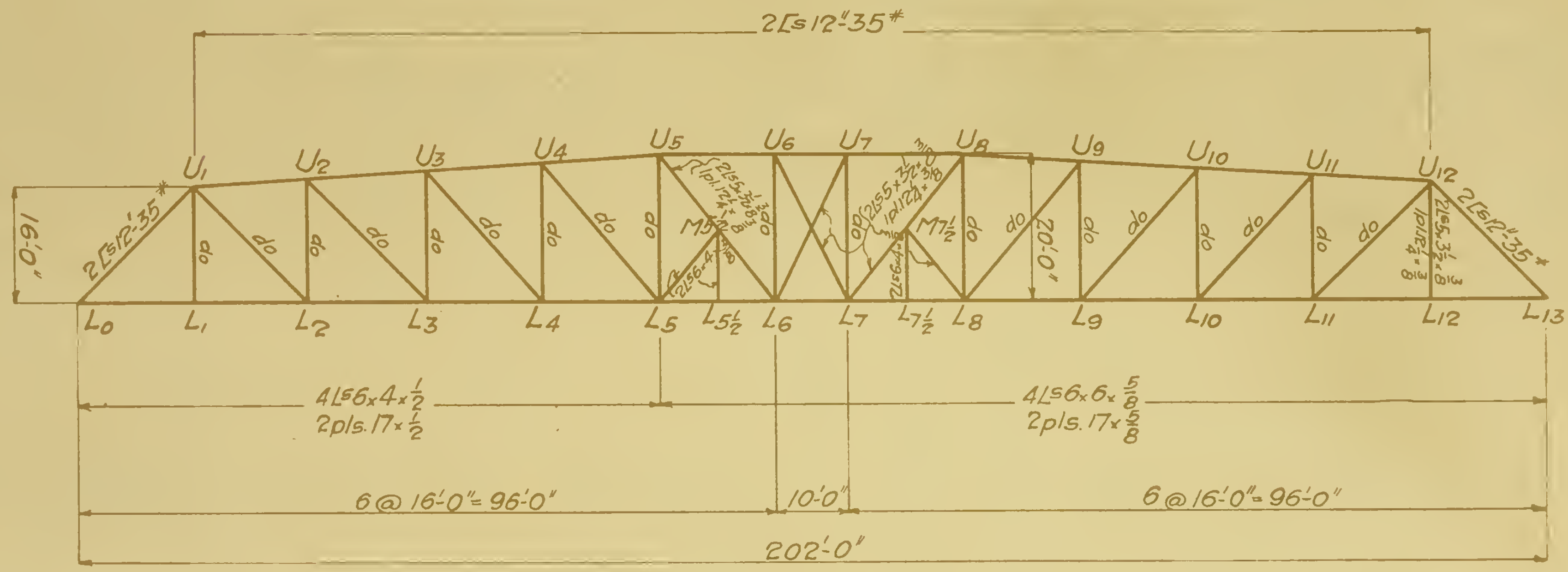
$\Sigma \frac{T^2L}{A} =$ 1551.6

For no deflection $R' = \frac{19,798,700}{1,551.6} = 12,760.$ $R'' = 21,300$ (1 arm)

For 1" deflection $R' = -\frac{0.340}{0.660}\, 12,760 = -6,580$ $R'' = 40,640$ (1 arm)

* Net areas, others are gross.

Tables showing stresses follow.



Brace Span.

Brace Span - Panel Dead Loads.

Loads for One Truss.

	Lo	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12	L13
Bot.Chord	2318	4636	2318			2614	4248	4248	2614			2319	4638	2319
" "			1970	3940	3940	1970			2303	4606	4606	2303		
Top "		917	1833	1833	1833	917			917	1833	1833	1833	917	
" "						1150	1871	1871	1150					
Portal		528											528	
Diagonals		601	601	647	647	735	735	735	735	647	647	601	601	
"			622	622	669	669	736	736	669	669	622	622		
"							545	545						
"						393	131	131	393					
Posts	1344	1344											1344	1344
"		991	1142	1207	1262	1316	1284	1375	1316	1262	1207	1142	991	
Laterals Top		88	176	88			68	68			88	176	88	
" "				93	186	186	93	88	176	176	88			
" Bot	340	340				329	329	329	329					
" "		329	657	657	657	329			329	657	657	657	657	329
Struts "	686	475	475	475	475	475			475	475	475	475	475	
x-bracing Top			440	448	403	403	403	403	403	403	448	440		
Knee Braces Top		100											100	
Hangers						257	257	257	257					
Mchy.Sup."A""D"							433	433						
" Gir. 1						262	1441	1441	262					
" " 2						328	328	328	328					
" " 3							560	560						
Center Diap.							3990	3990						
Field Riv.&Fills	175	350	350	350	350	350	283	283	350	350	350	350	350	175
Op. Mchy.							7970	7970						
Brake							247	247						
Walk(Timber)	500	1000	1000	1000	1000	1000	810	810	1000	1000	1000	1000	1000	500
Mchy.Ho "							2435	2435						
" " "							2615	2615						
	5363	11699	11584	11360	11422	13683	31812	31898	14006	12078	12021	11918	11689	4667
Loads assumed		11500	11500	11500	11500	11500	30000	30000	12000	12000	12000	12000	12000	
						L5 1/2=4400		L7 1/2=4400						

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Brace Span - Stresses etc.

Assumed live load=500# per ft. of bridge.

" " " =250# " " " truss.

Member	Stress. DL	LL	Dam.	Max.	Area	Unit Stress
LoL2	- 92.50	-23.25	±230.8	-323.30	*31.0	-10.43
L2L3	-163.29	-40.00	±313.7	-476.99	*31.0	-15.39
L3L4	-216.00	-51.33	±374.8	-590.80	*31.0	-19.06
L4L5	-253.48	-58.10	±414.1	-667.58	*31.0	-21.53
L5L6	-279.76	-61.80	+431.8	-711.56	*43.5	-16.36
L6L7	-304.24	-63.60	∓431.8 ∓702.00	+397.76 -736.04	*43.5	-16.92
L7L8	-280.96	-61.80	+431.8 ∓702.00	+421.04 -712.76	*43.5	-16.39
L8L9	-255.33	-58.10	+414.1 ∓702.00	+446.67 -669.43	*43.5	-15.39
L9L10	-218.13	-51.33	+374.8 ∓702.00	+483.87 -592.93	*43.5	-13.63
L10L11	-165.27	-40.00	+313.7 ∓702.00	+536.73 -478.97	49.7	+10.80
L11L13	- 93.80	-23.25	+230.8 ∓702.00	+608.2 -324.6	49.7	+12.23
LoLL1R	0.	0.	±167.8	±167.8	18.6	+ 9.02
L1RL1L	0.	0.	+120.0	+120.0	18.6	+ 6.45
U1U2	+163.49	+40.05		+203.54	20.6	+ 9.88
U2U3	+216.24	+51.39		+267.63	20.6	+12.99
U3U4	+253.74	+58.17		+311.91	20.6	+15.14
U4U5	+278.27	+61.06		+339.33	20.6	+16.47
U5U6	+304.24	+63.60		+367.84	20.6	+17.85
U6U7	+304.48	+63.60		+368.08	20.6	+17.87
U7U8	+304.48	+63.60		+368.08	20.6	+17.87
U8U9	+279.48	+61.06		+340.54	20.6	+16.53
U9U10	+255.60	+58.17		+313.77	20.6	+15.23
U10U11	+218.38	+51.39		+269.77	20.6	+13.09
U11U12	+165.46	+40.05		+205.51	20.6	+ 9.97

* Net areas, others are gross.

Brace Span - Stresses etc. (continued)

Assumed live load=500# per ft. of bridge.

" " " =250# " " " truss.

Member	Stress. DL	LL	Dam.	Max.	Area	Unit Stress
LoU1	+130.81	+32.88		+163.69	20.6	+ 7.94
U1L1	- 11.50	- 4.00		- 15.50	*13.0	- 1.19
U1L2	-104.93	-24.87		-129.80	*13.0	- 9.98
U2L2	+ 62.69	+13.58		+ 76.27	16.8	+ 4.54
U2L3	- 83.10	-18.01		-101.11	*13.0	- 7.78
U3L3	+ 49.00	+ 9.11		+ 58.11	16.8	+ 3.46
U3L4	- 63.49	-11.82		- 75.31	*13.0	- 5.79
U4L4	+ 35.94	+ 4.83		+ 40.77	16.8	+ 2.43
U4L5	- 45.66	- 6.16		- 51.82	*13.0	- 3.99
U5L5	+ 21.22	+ 0.71		+ 21.93	16.8	+ 1.31
U5L6	- 42.01	- 2.88		- 44.89	*13.0	- 3.45
U6L6	+ 0.60	0.		+ 0.60	16.8	+ 0.04
U6L7	- 0.67	0.		- 0.67	*13.0	- 0.05
U7L6	0.	0.		0.	16.8	0.0
U7L7	0.	0.		0.	16.8	0.0
U8L7	- 40.47	- 2.88		- 43.35	*13.0	- 3.33
U8L8	+ 19.97	+ 0.71		+ 20.68	16.8	+ 1.23
U9L8	- 44.68	- 6.16		- 50.84	*13.0	- 3.91
U9L9	+ 35.16	+ 4.83		+ 39.99	16.8	+ 2.38
U10L9	- 63.11	-11.82		- 74.93	*13.0	- 5.76
U10L10	+ 48.71	+ 9.11		+ 57.82	16.8	+ 3.44
U11L10	- 83.38	-18.01		-101.39	*13.0	- 7.80
U11L11	+ 62.91	+13.58		+ 76.49	16.8	+ 4.55

* Net areas, others are gross.

Brace Span - Stresses etc. (concluded)

Assumed live load=500# per ft. of bridge.

" " " =250# " " " truss.

Member	Stress DL	LL	Dam.	Max.	Area	Unit Stress.
U12L11	-105.95	-24.87		-130.82	*13.0	-10.06
U12L12	- 12.00	- 4.00		- 16.00	*13.0	- 1.23
U12L13	+132.65	+ 32.88		+165.53	20.6	+ 8.03
L5M5 1/2	+ 2.82	+ 1.28		+ 4.10	7.2	+ 0.57
L51/2M51/2	- 4.40	- 2.00		- 6.40	* 5.7	- 1.12
L71/2M71/2	- 4.40	- 2.00		- 6.40	* 5.7	- 1.12
L8M71/2	- 2.82	+ 1.28		+ 4.10	7.2	+ 0.57

* Net areas. Others are gross.

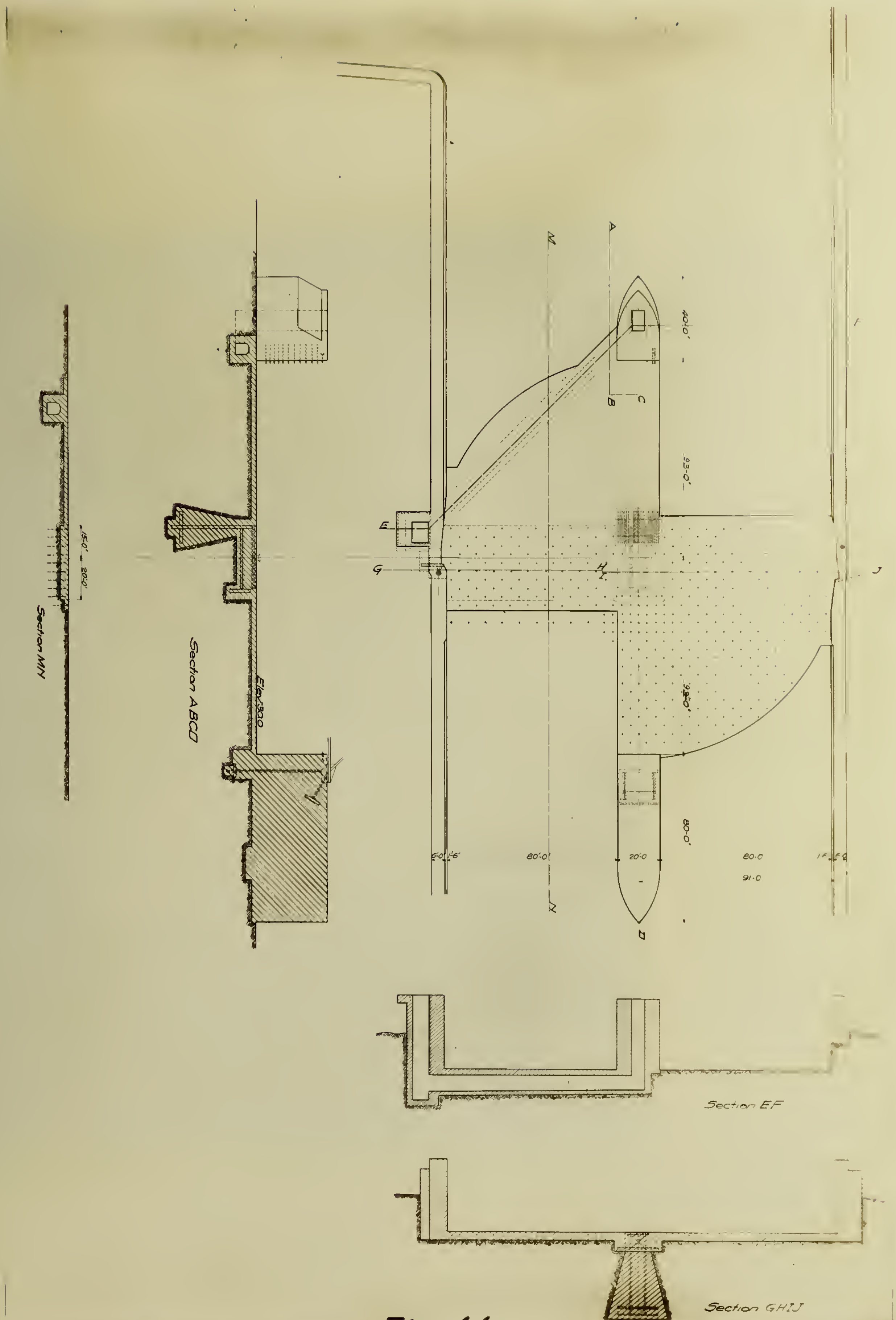


Fig. 44.

Fig. 45.

In foreground is view of pit for vertical grillage of lower pivot support looking east. The stone is channelled. On east side of pit it will be noticed that upper strata of rock have moved over lower strata for a distance of over 1". To the right are seen the vertical reinforcing rods projecting from solid rock and horizontal rods from the concrete. In the distance can be seen the east abutment steel during erection.

Fig. 46.

Pit for lower box girder. Vertical anchorage is seen projecting above floor of pit.

The maximum reaction to be carried by any bearing at either abutment is 202,000 pounds. This bearing is composed of horizontal 15" - 50#Ibeams, three at east and four at west abutment, which cantilever over a grillage of three vertical 15" - 50# I beams.

Fig. 44 shows general masonry design, and relative positions and proportions of the different parts. The reinforcing bars in floor of channel and steel imbedded in masonry are shown.

Figs. 45 and 46 show views of excavation for lower pivot anchorage.

In order to operate the movable leaf, the following forces must be overcome:-

1. To swing the leaf in 2.5 minutes - - - - -	9,500	ft.-lbs.
2. To overcome friction on pins and bearings -	100,000	"
3. To overcome impulse of moving leaf in water with a velocity of 1 foot per second - - -	350,500	"
4. To overcome friction of moving water on skin plates and end girder - - - - - - - - - - - - -	5,000	
	465,000	"

This turning moment is obtained by a force of 31,000 applied at each of two pinions to a rack 7.5 feet radius. In designing machinery these forces were taken at 70,000 pounds each and units increased.

All shafts were forged steel and all gears cast steel.

See Fig. 47 for layout of machinery. Only one set of machinery is shown in this diagram.

The tables on the following pages give designing figures and stresses in various parts.

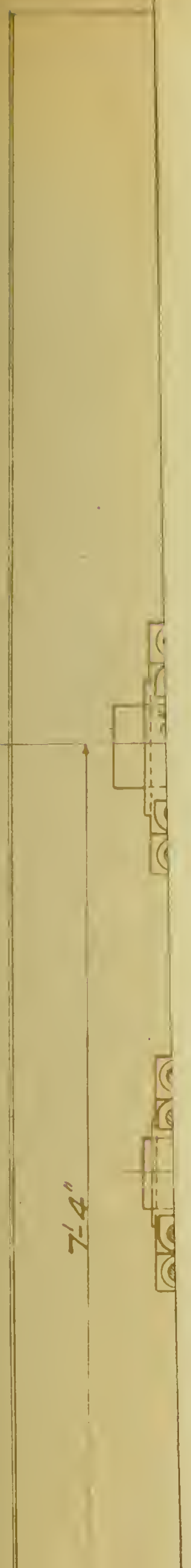
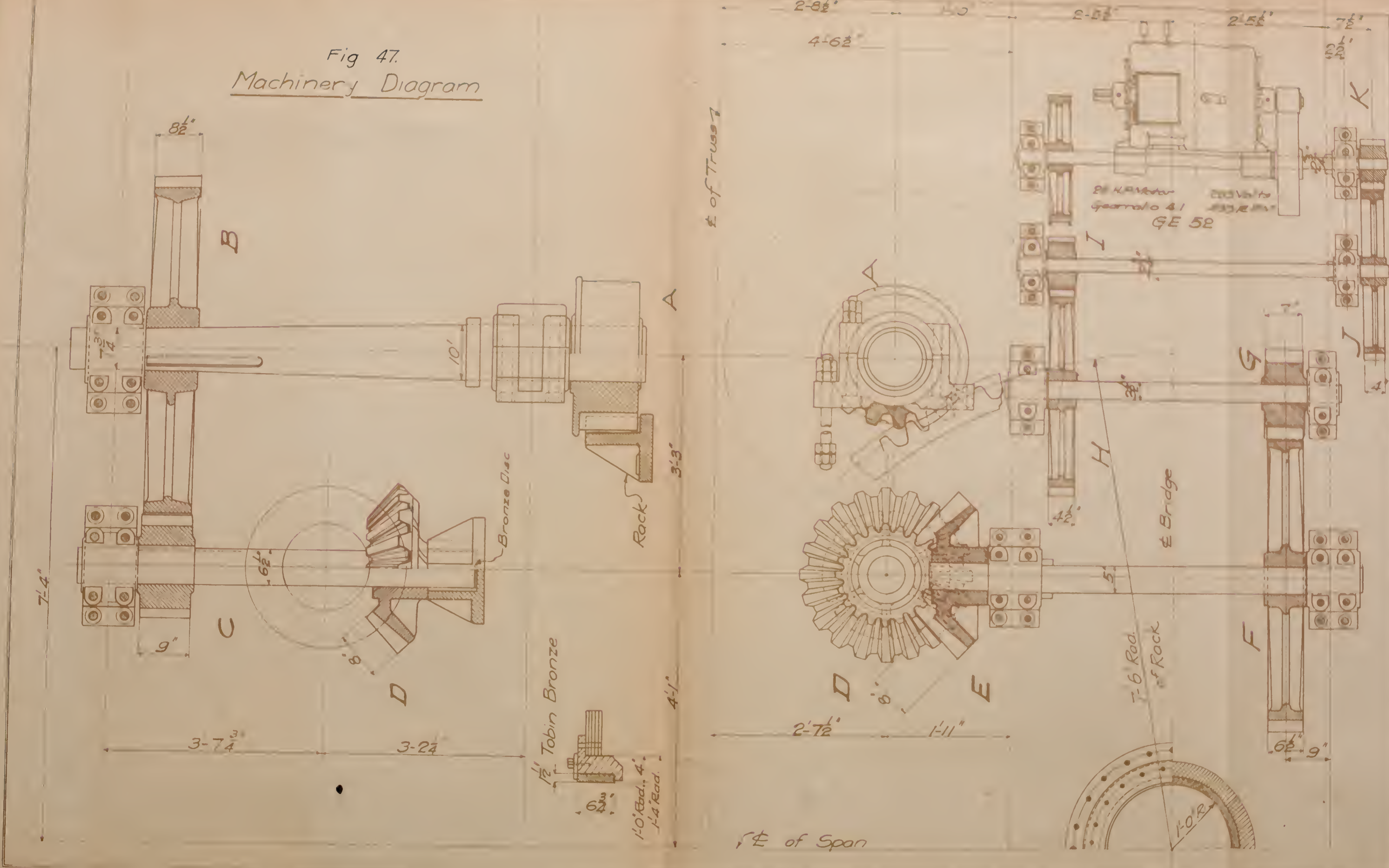


Fig. 47.

Fig 47.
Machinery Diagram



Gear	No. Reqd.	Pitch Cir. Diam.	Pitch	Face	No Teeth	Height of Teeth Above PL	Below PL	Total	Thickness of teeth at PL	Length of Hub	Bore	Keys
Rack	4Sec.	180.0	5	11.75	*23	1.25	1.75	3	2.313	-	-	
A	2	23.9	5	11.5	15	1.25	1.75	3	2.5	13.5	9.875	2-2.25x1.125
B	2	61.274	3.5	8.5	55	1.063	1.375	2.438	1.687	9	7.875	2-2x1
C	2	16.711	3.5	9	15	1.063	1.375	2.438	1.687	9.5	6.5	1-1.525x0.813
		16.538	2.594			1.344	1.719	3.063	2.063			
D	2	22.195	3.484	8	20	1.078	1.391	2.469	1.641	10	6.5	"
		27.852	4.375			0.812	1.063	1.875	1.219			
E	2	"	"	"	"	"	"	"	"	10	5	1-1.25x0.625
F	2	53.476	3	6.5	56	0.938	1.187	2.125	1.438	9.5	5	"
G	2	14.324	3	7	15	0.938	1.187	2.125	1.438	7.5	3.5	1-0.875x0.438
H	2	38.0	1.5D	4.5	57	0.625	0.813	1.438	0.969	5	3.5	"
I	2	10.0	1.5D	5	15	0.625	0.813	1.438	0.969	7.25	2.75	1-0.75x0.375
J	2	32.571	1.75D	4	57	0.563	0.687	1.25	0.844	5	2.75	"
K	2	8.571	1.75D	4.5	15	0.563	0.687	1.25	0.844	5	2.75	"

Gears H, I, J, and K have cut teeth.

* Each section.

Gear	RPM	Dia. of Shaft at Bearing	Length of Bearing	Unit Pressure on Bearing	Distance of Bearing	Pitch Line Pressure Moving	Pitch Line Pressure *Static	Bending Moment	Tortional Moment	Combined Moment	Unit Stress in Shaft	Unit Stress in Teeth
Rack	-	-	-	-	-	-	70000	-	-	-	-	#22000
A	0.759	10"	14"	500	14.5	-	70000	1015000	836500	2330000	11900	22500
B	0.759	7.75	10	405	9.5	31400	27300	350000	962000	1374000	15000	19500
C	2.78	6.5	9.5	508	9.5	31400	27300	259000	262400	627700	11700	18400
D	2.78	6.5	10	418	10	27200	20600	235000	301900	617600	11500	14400
E	2.78	5	10	544	10	27200	20600	272000	301900	678400	27600	14400
F	2.78	5	10	260	9.75	13000	8550	115000	347600	481100	19600	12300
G	10.4	3.5	7	530	7.25	13000	8550	86600	93100	213700	25400	11500
H	10.4	3.5	7	230	6	5640	3220	40200	107200	154700	18400	11100
I	39.5	2.75	4.75	432	6	5640	3220	29400	28200	70100	17200	10000
J	39.5	2.75	4.75	152	4.875	1990	990	9700	32400	43500	10700	5100
K	150	2.75	4.75	152	4.875	1990	990	9700	8500	22600	5500	4600

With pinion "K" running at 150 R.P.M. and a pitch line pressure of 1990# the H.P. = 20.3

* for comparison only

shrouded one side.

A high unit stress was used in designing shafts EF and GH so that if for any reason a greater load came on machinery than that used in designing, these shafts would be overstrained rather than shafts AB or CD, because if failure should take place, EF or GH are easier to replace. Gear teeth are made stronger throughout than shafting.

It would have been desirable to make rack of larger radius if it had been possible to support and protect same, but on account of infrequent use of dam it did not appear wise to add a large additional expense to secure the advantage. The machinery as designed and the stresses as calculated could have been taken care of by a 20 H.P. motor for each set. In actual operation 15 H.P. total will open or close the dam in less than five minutes. A maximum power of 35 H.P. total will operate dam in two minutes.

VI.

CONSTRUCTION.

At the time the design was being prepared, the specifications written and the contract made, it was presumed that Section 1 of the Water Power Extension, in which the site of Butterfly Dam is included, would be completed as regards the excavation of rock, and the building of the walls excepting such portion of wall as was to be omitted and constructed under the Butterfly Dam contract as the east and west abutments. If such had been the case, the entire site of Butterfly Dam would have been left as a clear channel excavated to elevation - 30 and with a width of 180 feet. The natural surface of rock is about elevation - 13. However, the actual conditions as they existed at the time of letting the contract were somewhat different, inasmuch as the channel was not completely excavated as is shown in Fig. 48.

In excavating channel the rock was channeled by a channelling machine, and the rock drilled and blasted. The material was removed by steam shovel and dinky train.

The rock in the vicinity of the site of Butterfly Dam is ordinary limestone, the surface rock being rather rotten. Vertical seams are frequent and the strata formation is quite marked. The layers are thin at surface, increasing in thickness with their depth. The lower rock is also harder and more flinty.

Fig. 48.

General view showing pit for anchorage of lower pivot support in foreground and breast of ground just beyond which is yet to be excavated.

Blue and green clay pockets occur irregularly between the strata.

Running diagonally across the site of dam is a vertical cleavage in the rock along which a slip of between two and three inches has taken place. These vertical cleavages are common in this vicinity, there being another within a few hundred yards. The entire rock formation appears to be under heavy lateral stresses. This was discovered when channelling center pit for lower box girder, a slip of one inch having occured at that time. This is shown in Fig. 45. This slip took place in an interval during which there was no blasting or other occurence which could have started same.

The rock excavation for abutments was carried the full depth of the latter, and vertical and oblique holes were drilled in floor and side rock, and reinforcing rods inserted and grouted in place. These reinforcing rods extended into the mass of concrete of abutments and thoroughly bound same to the rock. The abutments were extended to join and form part of the side walls of the channel. The side walls were placed on the solid surface of the material rock.

Great care was taken that the grillage beams and the horizontal beams, which carried the reactions from the movable leaf should be thoroughly imbedded in the concrete. Large holes were punched in all horizontal webs so that under side of beams could be completely filled with cement grout.

In order to have sufficient material for anchorage of skew back in down stream pier, it was necessary to excavate below floor of channel and it was also necessary to excavate to provide a dowel into floor of channel to prevent the pier from slipping bodily.The entire site of pier was excavated to elevation - 32

in order to have solid rock for foundation. In excavating original channel at times very heavy blasts were fired simultaneously which had a tendency to injure the rock below the necessary elevation - 30, bed of channel for Section 1.

The lower box girder at center pivot with its anchorage and grillage was set entirely below floor of channel. The rock behind the grillage which takes the greater portion of the horizontal thrust from the movable leaf was channelled, as were also the other sides of pit. In order to take care of the uplift from lower box girder, it was found necessary to carry down anchorage some 40 feet below floor of channel. This provided just enough weight to prevent uplift and also additional security against possible down stream motion by the dowelling effect of the concrete mass in the solid rock. The rock back of grillage is thoroughly bound together by rods in holes 11 or 12 feet deep.

The quadrants over which movable leaf swings were excavated two feet below bottom of channel, and an area running from abutment to abutment beneath movable leaf and extending 15 feet in front of same and 20 feet to the rear, was excavated to elevation - 34. Over the entire area of the quadrants and the last described surface, holes were drilled and reinforcing bars were set and grouted in place, thus preventing the pressure due to water between the strata of rock from raising floor of channel.

The up stream pier contains the shaft from the tunnel. Rock was excavated to elevation - 32 for base of pier and to elevation - 42 for bottom of shaft. The forms for shaft were made six inches larger all around than finished dimensions of shaft. After the pier was completed and these forms of shaft removed, forms of exact size of shaft were built, and a cement grout filled in.

Water proof lining was provided consisting of one part portland cement, and one and one-half parts screened sand.

In filling in the six inch shaft lining the drop of 25 or 30 feet would have destroyed ordinary forms. To prevent this, a loose two inch plank was hung on edge in the middle of six inch space by ropes from above. These pieces were raised as filling in progressed, keeping always about one foot above deposited material.

In original design, the tunnel ran square across channel to west wall, but owing to the fact that channel excavation was unfinished at time it was necessary to build tunnel, it was considered advisable and also an improvement in the design to place the west shaft in the west abutment, thus running tunnel diagonally across channel.

The sides of tunnel were channelled to full depth, this being done after floor of channel had been excavated to elevation - 32. Concrete floor of channel was laid first, after which forms for side walls were placed and walls built, these forms being six inches larger on either side than finished section. After walls had set, forms for finished section were placed and cement grout filled in side walls and covering top to a depth of six inches. The concrete on top of this forming floor of channel was placed immediately, thus obtaining complete bond between waterproof lining and floor. See Figs. 49 and 55.

The shaft in west abutment was constructed similarly to the one in up stream pier. A drain extends full length of tunnel, terminating in a sump at bottom of west shaft where a pump is located.

The plant used in substructure work consisted of one channell-

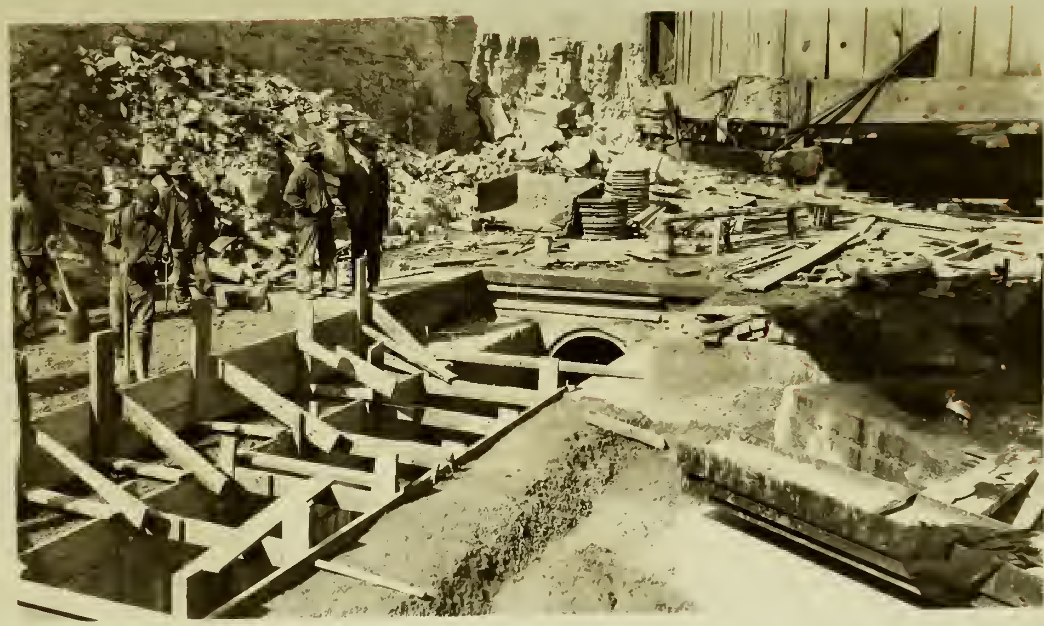


Fig. 49.

General view of tunnel under construction.

ing machine, one concrete mixer, a number of service cars and a portable track, an inclined trestle and cable haulway, a Page revolving derrick and bucket, and a derrick and incline for furnishing rock to concrete mixer. The former derrick was also used as a derrick proper for upper parts of piers and abutments. See Fig. 50

Owing to the great loads that had to be carried by the steel work in this structure, it was necessary to use the maximum sizes obtainable and capable of shipment after fabrication. 8"x 8" angles were used quite extensively throughout the work, together with 7/8" plates, some of which were 132" wide by 15 to 18 feet long. All material used was medium open hearth steel, with a tensile strength of from 60,000 to 68,000 pounds per square inch.

As the time available for the completion of dam was very limited, great care was taken to order from such mills as could make immediate shipments.

Some special shop machinery was required on account of the large sizes of material and of fabricated parts. See Figs. 13, 18 and 19. The heavy diaphragms for bearings of pivots were composed of seven-eights inch plates, which were assembled and drilled in the solid. High speed portable drills were made use of, operated by motor direct. One inch diameter rivets were used in these plates, and a 100,000 pound direct pressure rivetter drove same.

The pin holes for pivots were bored by a portable boring machine somewhat similar in design to those used in boring cylinders of locomotives in place. This machine was driven by motors direct connected to same.

The bronze bushings in the castings for upper pivot support

Fig. 50.

Page revolving derrick and bucket used in loading rock onto dinky cars.

In distance is incline for concrete mixer.

were forced into place by direct hydraulic pressure of about 50 tons. The supporting casting for the bushing was forced into diaphragm of brace span by a number of one inch bolts close to casting on inside of pivot hole. By turning down the nuts on these, an estimated pressure of from 40 to 60 tons was used.

All material five-eights inches thick and over was sub-punched and reamed or drilled in the solid. All field connections were reamed in the field. About 65,000 holes were reamed in the field.

All material was inspected at mill or foundry and at shop and in field. Complete tests were made of each and every class of material and of every heat. In some instances test bars were taken from special individual pieces.

The following table gives the weights of the material used in the entire structure:-

Structural steel -		
Anchorage		
East abutment	18,742	
West "	20,306	
Up stream pier	30,291	
Down " "	69,714	
Lower pivot	195,825	334,878
Stairways-N and W shafts		7,170
Brace span		311,780
Movable leaf		
Center box girder	193,731	
Girder #1	97,462	
" #2	112,868	
" #3	97,668	
" #4	97,264	
" #5	78,831	
" #6	57,774	
" #7	57,556	
Footwalk etc. on Girder #7-	18,401	
Motor supports etc. " #7-	5,178	
End girders	30,641	
Cross frames & diaphragms	183,447	
Sheathing plates	136,132	
Gusset plates	5,774	
Lateral plates	13,337	
Diagonal bracing	29,512	
Zee bars	19,670	

(con.) Valve frames & plates	20,128		
Lock lever	702		
End lock(steel only)	6,805		
Field rivets	45,222	1,308,103	
Total structural steel -		1,961,931	
Machine steel castings etc.			
Upper pivot shaft		14,070	
Lower " "		18,955	
Upper pivot rod and rings		1,545	
End lock and lever		18,915	
Operating machinery		41,331	
Valve "		51,133	
Pump "		900	
Stairways-N and W shafts		6,983	
Total machine steel etc. -		153,832	

Lumber - about 30,000 board feet.

Earth excavation	142.0	C.Y.
Rock excavation	6230.8	"
Channelling	3805.6	Sq. ft.
Concrete 1:2 1/2:4 1/2	4213.6	C.Y.
" 1:3:6	4027.9	"
" Grout	32.8	"
Granolithic surfacing	956.8	Sq. yds.
Drilling	4059.0	Lin. ft.

Fig. 51.

In right foreground is south pier, A-frame traveller and center box girder in middle. Service track and dinky cars with Page revolving derrick loading same. In the distance on floor of channel is a derrick just beyond which is trestle. In extreme distance to left is a stiff leg derrick used to pick up stone in skips from scows in main channel. Stone is dumped in stock pile from which it is filled into hopper by revolving derrick. From this hopper cars are loaded and hauled by cable up incline and dumped into concrete mixer.

Fig. 52.

General view showing lower pivot anchorage ready to be lowered. Rocker arm bent in distance.

The shipping weights of some of the parts are the maximum ever fabricated to the best of the author's knowledge. Owing to the short length of these pieces, it was with some difficulty that cars of sufficient strength were secured to transport them . The center box girder was transported on two cars, practically 80,000 pounds being carried on one truck of a 100,000 pound capacity car.

For erection, the material in the field was delivered from a spur track to the east wall of channel some 200 feet north of center pivot. It was necessary therefore to transport the steel from top of wall to floor of channel and down to dam. Two derricks were used in unloading lighter pieces from cars and to floor of channel. In handling lower box girder and center box girder, it was necessary to provide means of greater capacity both in lowering and setting same. An A-frame traveller with inverted A-frame legs, as is shown in the illustrations, was employed. See Figs. 51 and 52. The derrick was used in conjunction with traveller to let the lower box girder down to floor of channel. The center box girder was handled in somewhat different manner. A trestle was extended out from walls of channel, cars with center box girder were run out over same, and by means of two triple blocks and falls attached from traveller and one from derrick, the box girder was lifted from cars. Latter were then withdrawn, trestle bents were torn down, girder lowered to floor of channel, and skidded on runway to position for setting on end and placing on lower pivot. See Figs. 53, 54, 55, and 56. This traveller was also used in erecting the several horizontal girders of movable leaf and the brace span as is shown in Figs. 57, 58 and 59. As the movable leaf is made of a number of fabricated parts

Fig. 53.

Center box girder suspended from falls of A-frame traveller and derrick, by which it was lowered to floor of channel. Trestle bent can be seen below lying on floor of channel.

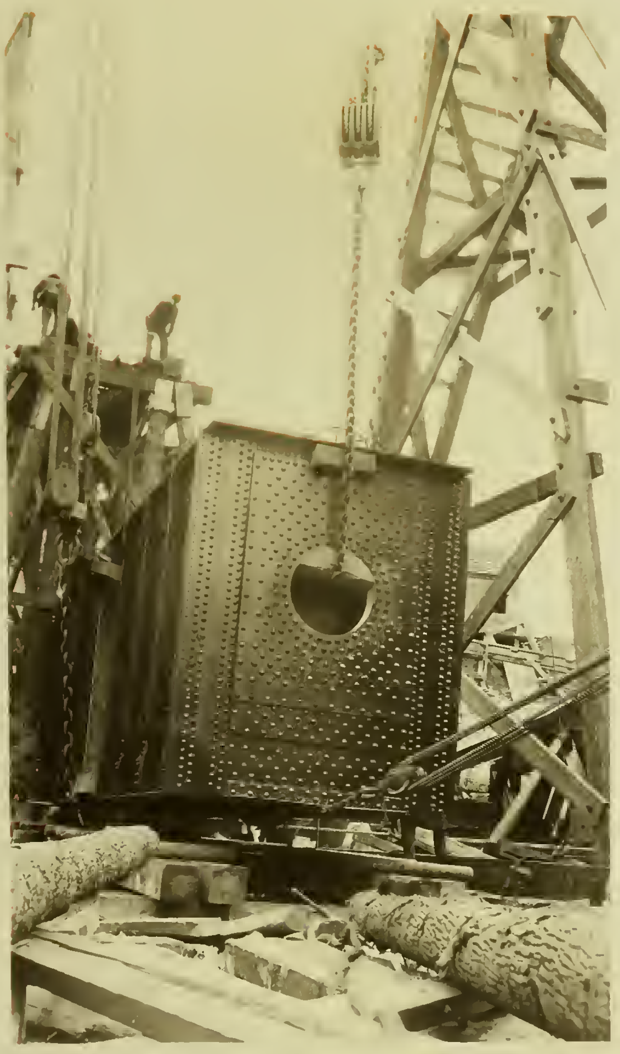


Fig. 54.

Center box girder just prior to being landed on rollers of skidway.

Fig. 55.

Center box girder being moved on skids around north pier. Forms have not been removed from pier. In center, channel, cut for tunnel is plainly seen as is also the end of finished tunnel.

Fig. 56.

Center box girder in same position as in Fig. 50. North pier forms are clearly shown. Also top of forms for shaft. The channel below Butterfly Dam is shown. In the distance is seen Ninth street bridge, Lockport.

Fig. 57.

Center box girder and girders #1 and #2 in position. Skew back on top of down stream pier is clearly shown. In the distance are the controlling works, bridge over Bear trap dam, frames for seven completed sluice gates and masonry for eight uncompleted.

Fig. 58.

General view during erection of movable leaf.

Fig. 59.

General view during erection of movable leaf.

which must work together as a unit, all field connections were reamed in field. This hastened time of completion and final adjustment was as nearly perfect as possible. Figs. 60 and 61 are detail views taken during erection of leaf.

The movable leaf, when completed and allowed to swing free across channel, was one-half inch lower at east end than at west end. This was due to unbalanced weight of end lock and castings amounting to about seven tons, and was rectified by placing a block of concrete in west arm. Face of movable leaf was in as true plane and alignment as could be wished. To avoid possibility of a warp, care was taken to camber front and rear in different degree.

In addition to traveller and derricks mentioned, two hoisting engines and a complete air plant for drilling, reaming and riveting was used.

Fig. 60.

Detail view during erection of movable leaf.

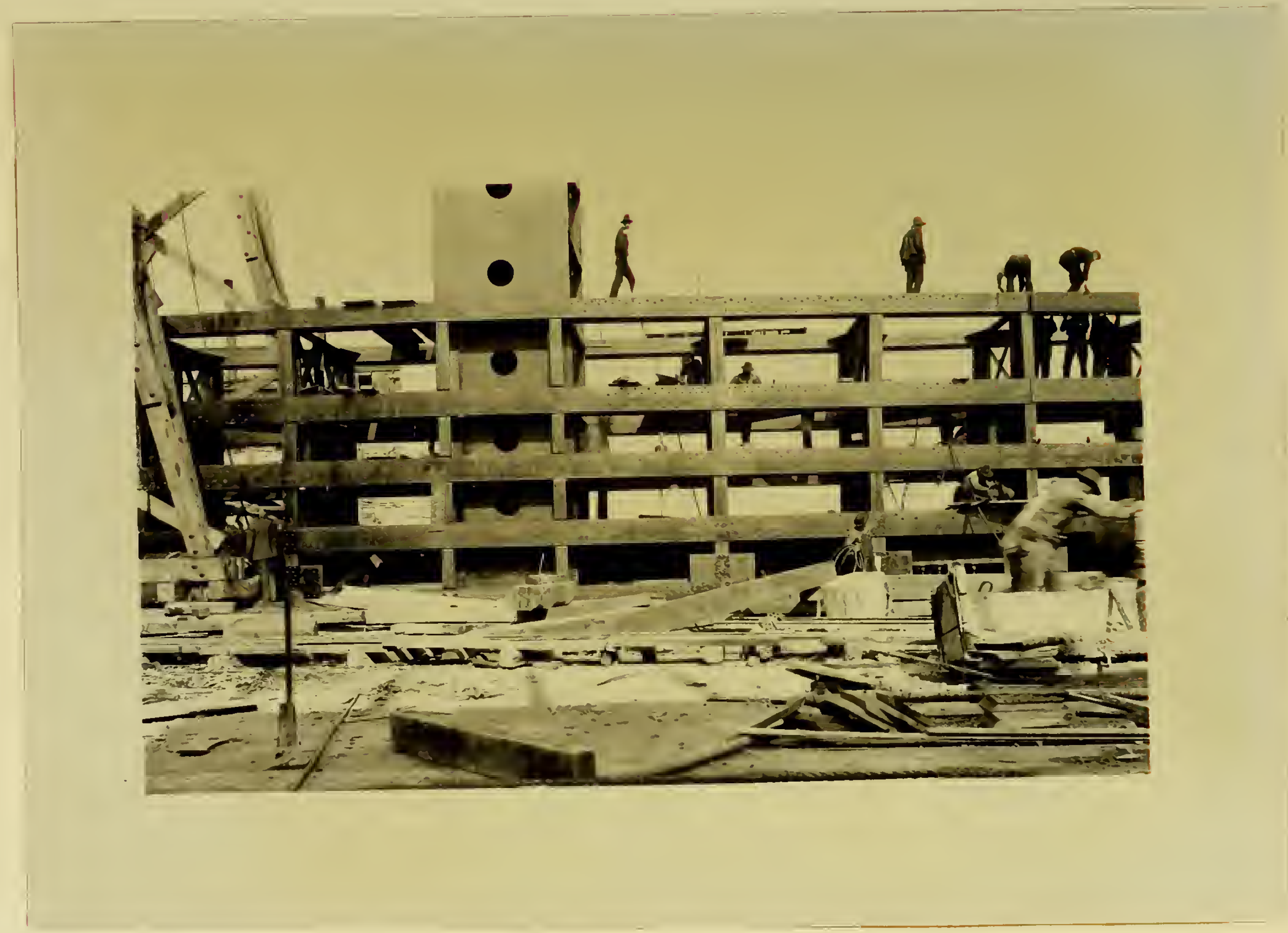


Fig. 61.

Detail view during erection of movable leaf.

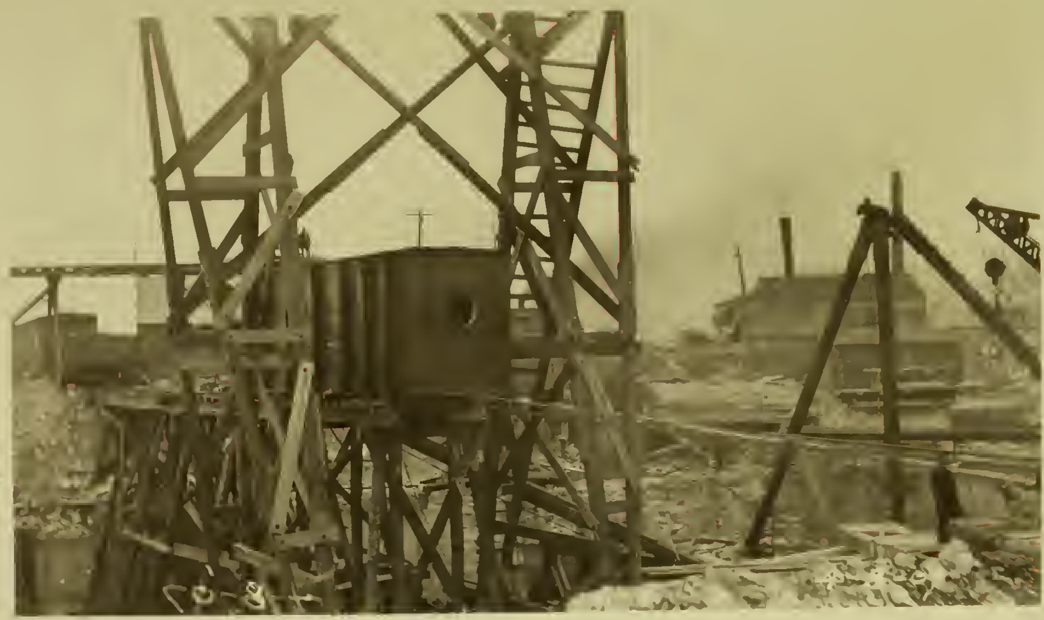


Fig. 62.

Center box girder on trestle previous to being lowered.

Fig. 63

Center box girder being lowered. Forms partially completed for up stream pier. Anchorage for rocker arm is plainly shown.

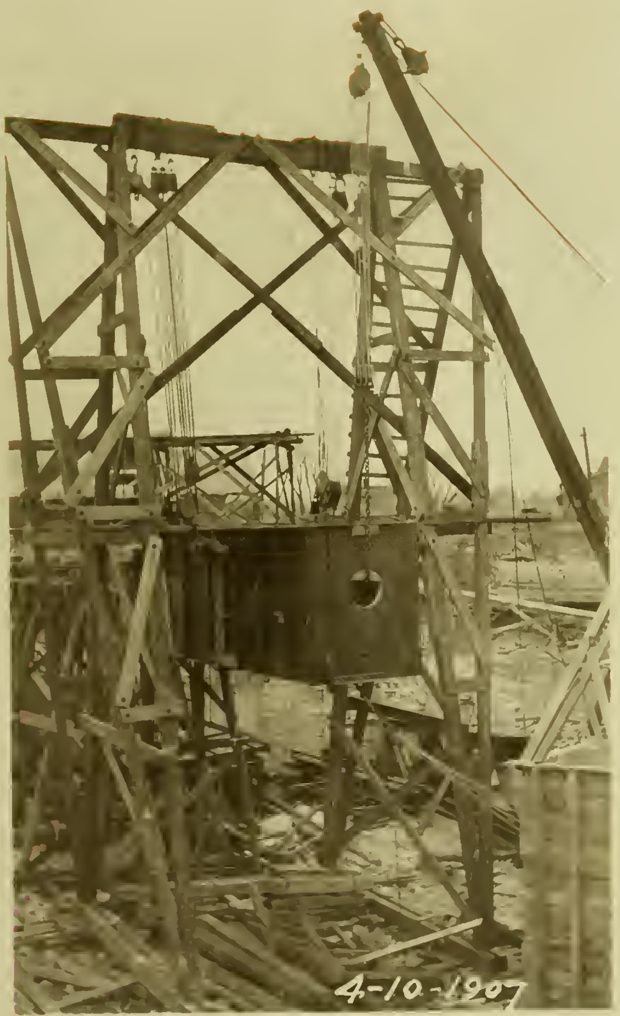


Fig. 64.

Center box girder entirely supported by traveller and derrick. Trestle bents are lying on floor of channel.

Fig. 65.

Center box girder being upended just previous to being placed over center pivot.

Fig. 66.

Another view of center box girder as it is being raised at center pivot.

Fig. 67.

Down stream pier in foreground. Movable leaf as erected under brace span, up stream face.

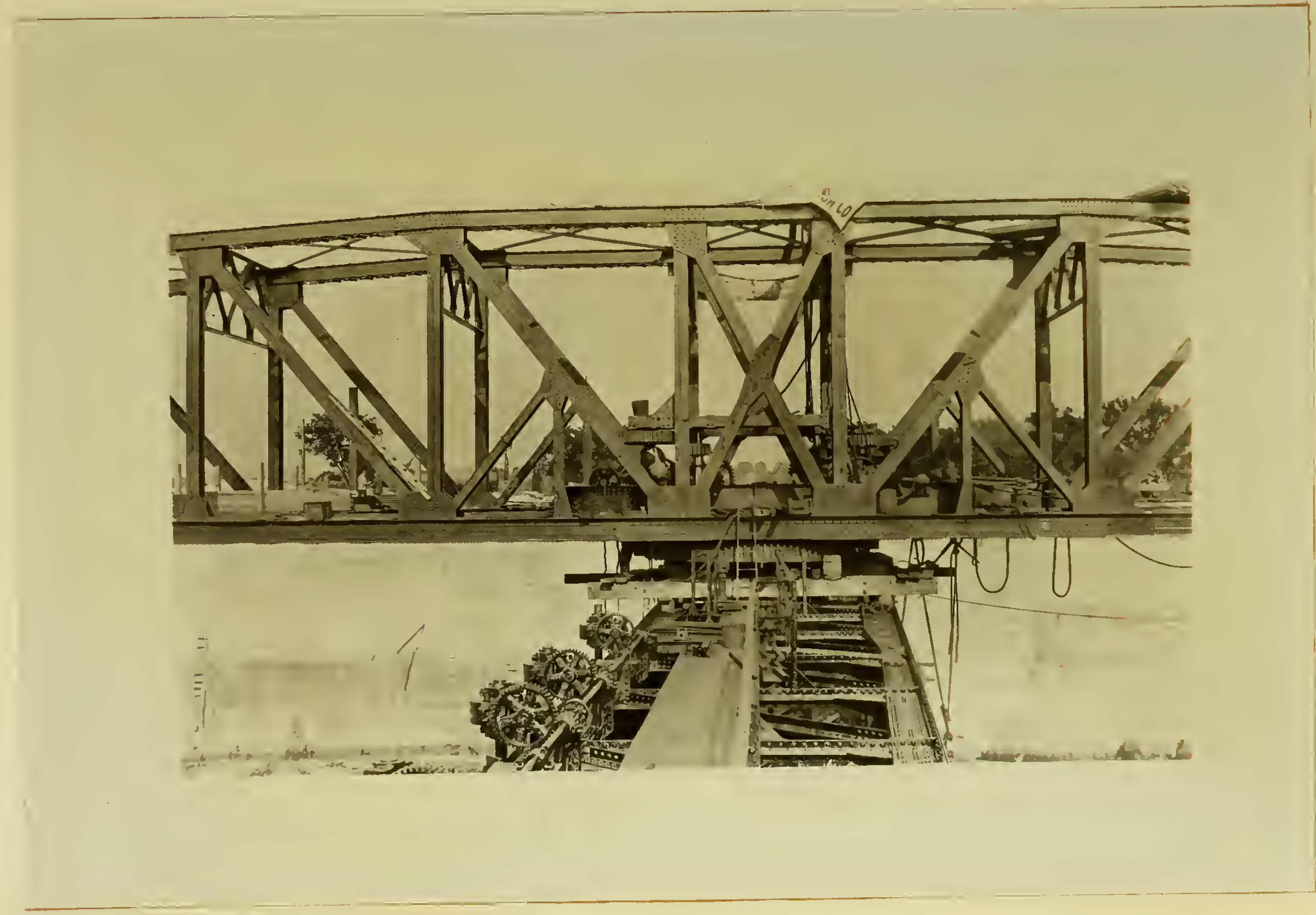


Fig. 68.

Movable leaf across channel.

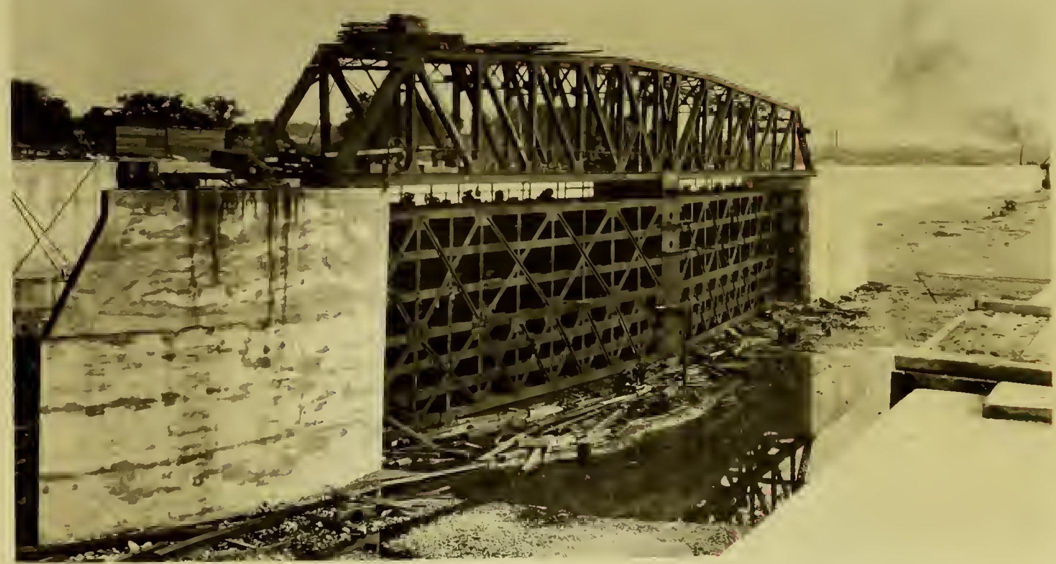


Fig. 69

Up stream pier in foreground. Down stream face of movable leaf.

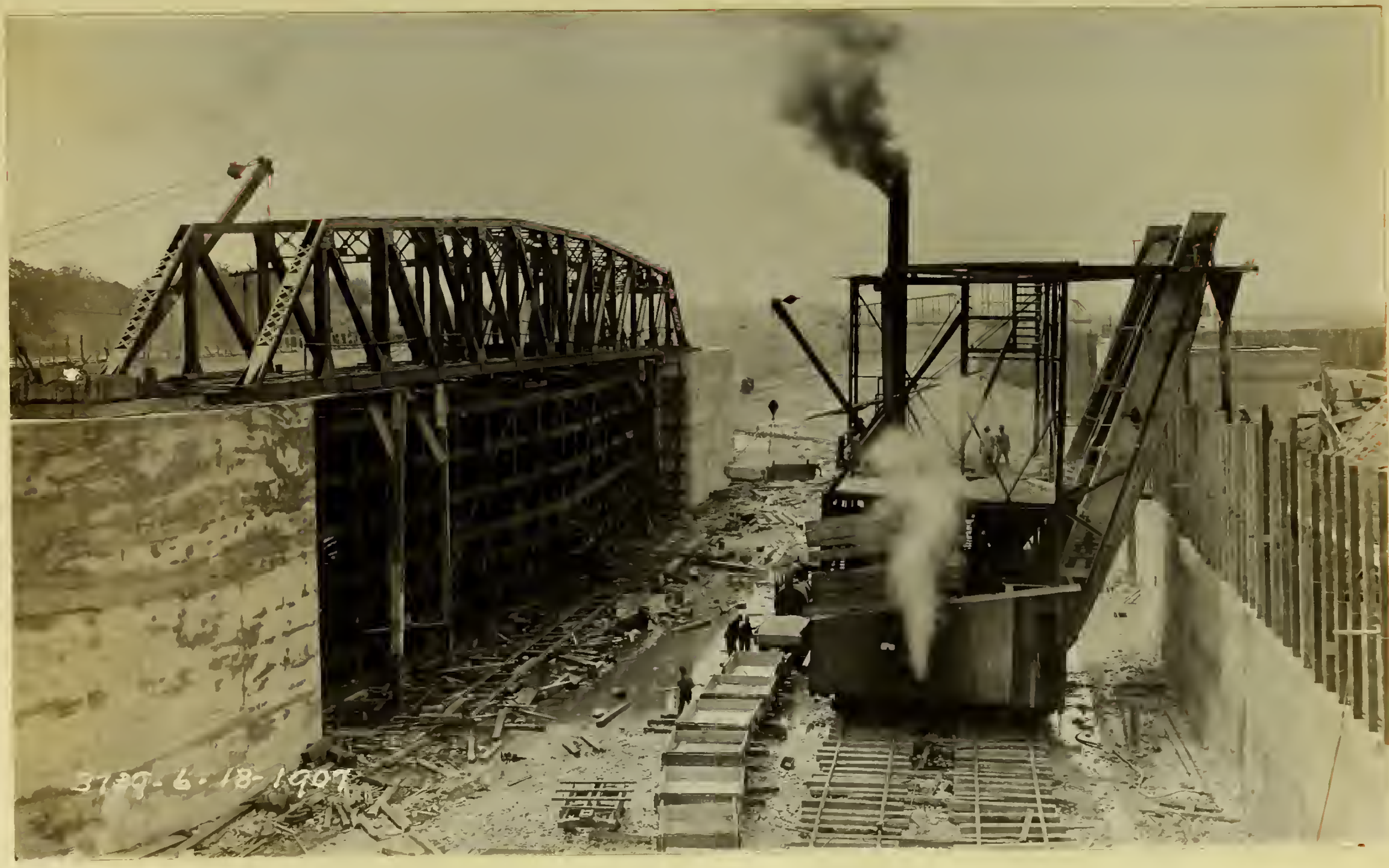


Fig. 70.

Brace span nearly completed. On the right is a Sanitary District concrete mixer building west wall.

Fig. 71.

Valve machinery during erection. General view of up stream face of movable leaf. Guard plate for valve shafts can be seen plainly.

Fig. 72.

General view of down stream face of movable leaf.

Temporary mud dam in distance.

Fig. 73.

General view of up stream face of movable leaf.

Valves in closed position.

Fig. 74.

Movable leaf in closed position just prior to opening of valves. Water on up stream side at datum.

Fig. 75.

Same as Fig. 74, excepting that all valves are open.

Fig. 76.

All valves open,controlling works in distance.

Fig. 77.

General view of dam from down stream. Valves on east half of leaf fully open; on west half valves but partially open. Dredge in distance excavating mud dam.

Fig. 78.

Channel fully filled. Butterfly Dam nearly open.

Dredge in distance excavating mud dam.

Fig. 79.

Leaf in closed position. Operator's house clearly shown.

Fig. 80.

Up stream pier in foreground, movable leaf in closed position.

Ninth Street bridge, Lockport, in distance.

Fig. 81.

Movable leaf in open position. Dredge in distance excavating mud dam.

VII.

CONCLUSIONS.

A general description has been given of the drainage canal, and more especially of the construction near the controlling works and the power house, and the necessity of a device of the nature of that herein described has been discused.

Mr. Isham Randolph, Chief Engineer of the Sanitary District at the time the Emergency Butterfly Dam was constructed, says in an article before the Western Society of Engineers, "We have built with a view to such permanence that a safety device should be unnecessary, but to give every assurance to any timid people, apprehensive of a catastrophe from this body of water, a safety appliance had to be devised and one that would not interfere with the waterway."

It is to be hoped that such a contingency will never arise, and that the dam will be needless as far as its main purpose is concerned. However, there is not the slightest doubt that the structure is entirely capable of performing whatever service may be required of it, as was satisfactorily demonstrated at the time the mud dam was removed, and the waters of Lake Michigan first reached it.

The component parts have been described and illustrated. A number of these details are peculiar to the nature of the design, and are used here for the first time - notably, the end lock, the

longitudinal brace span, the rocker arm, the skew back, the lower pivot support and anchorage, and the special steel work in abutments.

The various ways in which the movable leaf may receive its load have been discussed and the stresses computed for these various loadings. High unit stresses are found to be used with the infrequent and less probable loadings, in accordance with usual practise. The down stream pier is unusual in that its main load is a horizontal thrust.

The points that stand out prominently in connection with the construction are the sizes and weights of the fabricated parts combined with the accuracy required of a machine.

The general contract was awarded to the Strobel Steel Construction Company, who made shop drawings and mill orders. They also erected the steel work. The rock excavation and channelling and the masonry were sublet to Page and Schnable; the electrical equipment and pumps to George P. Nichols & Brother; the shaft houses and machinery house to W. & S. Nelson. The fabrication of the steel was sublet to Smeeth Company, and the machinery to the Hanna Engineering Works. The Bethlehem Steel Company furnished the hydraulic forged pivot shafts.

Owing to the magnitude of the work and the unusual construction, specifications were written which required the highest quality and the most modern methods of construction. By requiring high class work, results were obtained which were highly satisfactory. All the contractors on this work, without exception, endeavored to furnish the best work their shops were capable of doing. Work was carefully inspected at mill, in shop and in field by the Pittsburg Testing Laboratory. The designing

engineer kept in very close touch with work at all times.

The general scheme of the Emergency Butterfly Dam was originated and proposed by Mr. Isham Randolph, as Chief Engineer of the Sanitary District, and the design and details were made in the Bridge Department, Mr. C. R. Dart, Bridge Enbgineer, and Mr. S. T. Smetters, Assistant Bridge Engineer. The shop drawings were made under the direction of Mr. Theodore Rall, Chief Draughtsman of the Strobel Steel Construction Company. The fabrication of steel work was under charge of Mr. C. A. Fingel, Chief Engineer of Smeeth Company. Mr. S. J. Fitzpatrick, Superintendent of the Strobel Steel Construction Company, with Mr. Joseph Kline as foreman, erected the steel. Mr. John B. Quinn was in charge of masonry for Page and Schnable. Mr. William M. McCartney, Assistant Engineer of the Sanitary District, was resident engineer.

The total cost of the Butterfly Dam was $220,000. Butterfly Dam was built at less cost and is operated more quickly than any other movable dam of equal magnitude or performing the same functions. The contract was let July 27, 1906, and was completed August 27, 1907, at which date the temporary mud dam was broken.

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